NASA Earth Science Enterprise
Earth Science Applications Directorate
San Diego State University Research, Education, and Application Solutions Network (REASoN) Project

Final Report:
A Border Security Spatial Decision Support System Driven by Remotely Sensed Data Inputs

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1.0 Introduction and Project Objectives

Following the events of September 11, 2001, the United States Border Patrol (USBP) has been increasingly concerned with enhancing homeland security by minimizing the flow of people or materials across our borders that may facilitate terrorism. The USBP is committed to the utilization of new and advanced technologies for monitoring and enforcement within the border region. In particular, the agency is interested in implementing geo-spatial technologies such as remote sensing, geographic information systems (GISs), global positioning systems (GPSs), and spatial decision support systems (SDSSs) to assist them in better securing our borders. The USBP is dedicated to the implementation of a national border security decision support system that will increase their ability to secure the U.S. border and increase the efficiency, productivity, and safety of agents.

The objective of this project was to extract information and knowledge content from remotely sensed imagery and geospatial data and assimilate such information into a SDSS for use by border security agencies in securing U.S. borders to prevent and reduce America's vulnerability to terrorism and smugglers. A team of Homeland Security, state and local law enforcement and resource agencies, researchers from San Diego State University (SDSU), and remote sensing technology companies collaborated on this project. The SDSU Department of Geography and the San Diego Sector of the USBP were the principal partners. The San Diego Sector of the USBP is the leading sector in the US for development of advanced capabilities and innovation pertaining to geo-spatial technologies and border security issues.

The project team developed data products and information extraction algorithms for the USBP SDSS that may be utilized by all levels of the USBP and collaborating local, state, and federal agencies to tactically and strategically allocate and disseminate personnel and technology resources for securing the international borders of the US. Key data sets and information products of the SDSS were derived from remote sensing and image processing techniques that have been developed through this and past NASA sponsored research efforts.

While the scope of this REASoN project was broad, efforts may be categorized into five primary research areas: 1) high spatial resolution remote sensing; 2) moderate spatial resolution remote sensing; 3) GIS analysis and modeling; 4) wireless mobile GIS and integrated web GIS; and 5) apprehension demographics, data mining and geospatial visualization. An overview of each of these topics and resulting key accomplishments are provided in Sections 2.1 through 2.5. A complete listing of all project outcomes (including theses/dissertations, refereed publications, conference proceeding papers, project reports, technical briefing or training documents, software tools, academic reports, and derived maps and/or data sets) is provided in Section 2.6.

Implementation and utilization of the diverse range of algorithms and data products that resulted from this REASoN project is an ongoing effort. As indicated in Section 3.0, the Border Intelligence Center (BIC) of the USBP San Diego Sector is working to implement most of the products that resulted from the project. The potential benefits of this REASoN project and its outcomes for the USBP include new information/intelligence, improved situational awareness, increased interdiction success, and improved safety. A web portal with online materials (reports,

tools, data, etc.) is accessible by the USBP to support technology transfer. In addition, specialized training has been provided to the USBP San Diego Sector.

While the NASA REASoN project is completed, the Department of Geography at SDSU continues to perform geospatial border research as a principal founding member of the Department of Homeland Security National Center for Border Security and Immigration. This research has five major components: (a) analysis of the physical geographic landscapes of the US borders in terms of the potential for smuggling and the ability to monitor smuggling activities using a network of ground-based and remote sensors, (b) assessment of the institutional setting within US Border Patrol (BP) and other DHS line agencies for implementing decision-support (i.e., command and control) systems, (c) matching available and appropriate communication, computing, and geo-spatial technologies to the physical geographic and institutional landscapes characterized in a. and b. above, (d) developing a prototype remote image changed detection and monitoring system, and (e) leveraging of COE funding to develop collaborations for conducting demonstration projects with industry and university partners. We are analyzing high-spatial resolution image and digital elevation data to characterize and segment both borders, in the context of implementing image-based change detection of smuggling infrastructure (e.g., trails, tunnels, clandestine landing strips).

2.0 Key Accomplishments and Outcomes

Key accomplishments and outcomes are provided individually for each of the five primary research areas. Each section begins with a description of the research area, followed by a brief summary of accomplishments under this research area. Outcome documents are then listed, and the abstract and conclusions from these documents are provided to give a general overview of the research and findings. Full length documents (in PDF format) are listed by name, and are available upon request. Please contact Lloyd (Pete) Coulter (lcoulter@geography.sdsu.edu) or Doug Stow (stow@mail.sdsu.edu) in order to obtain any of the full length documents.

2.1 High Spatial Resolution Remote Sensing

This general task pertains to techniques for generating precise image mosaics covering the border tactical zone at very high spatial resolution, several times per year, and for efficient extraction of land surface features of interest to USBP from this imagery. Elements of this general task include evaluation of various sensors and sources of high spatial resolution multispectral image data, geometric and radiometric pre-processing requirements for generating multitemporal data sets having high fidelity, and evaluating interactive and semi-automated approaches for delineating trails and other land surface features associated with smuggling operations.

2.1.1 Key Accomplishments

The SDSU REASoN team contracted the collection of 0.15 m (six inch) color infrared aerial photography in May 2004, March 2005, and July/August 2005, and utilized this imagery to evaluate and demonstrate the utility of high spatial resolution imagery for border monitoring. The image sets were spatially co-registered with high precision using a technique developed by our team. This technique referred to as "frame center matching" is based around the idea of matching camera stations between multitemporal acquisitions so that the air base between corresponding multitemporal image frames is essentially zero and parallax is minimized. When image frames are acquired in such a manner, they may be spatially co-registered with high accuracy using a variety of basic image processing procedures.

The May 2004 image set was utilized to create a baseline trail map for the entire 100 km (60 mile) length of the San Diego County segment of the international border. This baseline image set provides valuable information to the Border Patrol, and it may be used to assess changes in trails over time. The baseline trail map was created through interactive digitizing by analysts. We also evaluated semi-automated techniques for creating trail maps (Kaiser et al., 2004; Cao et al., 2007)

We evaluated semi-automated approaches for detecting and delineating new trails and other land surface features associated with smuggling operations (Lathrop 2009). The utility of Feature Analyst, Definiens (previously eCognition), and a modified road extraction model implemented using ERDAS Imagine Spatial Modeler for delineating new trans-border trails using multitemporal image difference products was tested. Multitemporal images derived from scanned color infrared film acquired in May 2004 and July 2005 with 0.15 m (6 inch) spatial resolution was used. The multitemporal image sets were co-registered with very high precision (1-2 pixels with 6 inch resolution) using the frame center matching technique described previously (Coulter et al., 2005). Study sites in Marron Valley and Bell Valley (near Tecate, CA) were selected and difference images were processed through the software routines to evaluate how well each tool could extract the new trails, and minimize errors and confusion with features other than new trails. Conclusions were drawn regarding the strengths, weaknesses, and ease of use of Feature Analyst, Definiens, and the custom ERDAS Imagine Spatial Modeler software. Feature Analyst was easiest to use with Definiens and the ERDAS Imagine Spatial Modeler increasingly complex, respectively. Feature Analyst is recommended for novice to advance users.

The collection, processing, and analysis of imagery as part of the REASoN project allowed the San Diego Sector of the US Border patrol to utilize remote sensing and derived products in their operations. To assist the Border Patrol in extending the applications of remotely sensed imagery across US land borders nationwide, the team surveyed leading companies in the United States operating large format digital sensors (ADS40, DMC, and UltraCam) onboard airborne platforms to assess imagery technical specifications and relative costs (Coulter et al., 2009). Several companies who completed the survey also collected custom demonstration data sets for evaluation and comparison. The project team evaluated and compared the spatial, spectral, and radiometric characteristics of the demonstration data sets. As part of this high spatial resolution

image assessment, we found that large format digital imagery from the commercial vendors could be precisely co-registered (within 0.3 m) using the frame center matching technique if specific processing procedures are followed (Coulter and Stow, 2008). Information derived from the survey, from technical specification sheets, and from the evaluation of the demonstration data sets was utilized to make recommendations to the US Border Patrol regarding appropriate sensors and data processing techniques.

Several satellite sensors provide high spatial resolution imagery. We evaluated QuickBird panchromatic and pansharpened imagery as a source of imagery for interactively delineating trails. We also simulated QuickBird resolution imagery (0.6 m) from our high spatial resolution image set (0.15 m), to determine of QuickBird imagery could be utilized in a change detection mode for semi-automated delineation of new trail. Two separate studies performed as part of the SDSU REASoN project found that high spatial resolution satellite imagery with 0.6 m spatial resolution is too coarse for effectively mapping trails on single date imagery or for detecting trail changes using multitemporal imagery.

Collection of aerial and satellite imagery is often expensive and may not be very timely due to contracting procedures, sensor availability/overpass time, and narrow time windows with appropriate weather conditions. Light sport aircraft (LSA) and micro unmanned aerial vehicles (micro-UAVs) may be used to quickly and safely collect ultra-high spatial resolution imagery (e.g., 1 cm spatial resolution) at low cost. Such high spatial resolution imagery can useful for change detection and detailed reconnaissance of features with limited extents (tunnel entrances/spoil piles, trails, hide-outs, etc.). Small platform/sensor combinations may also be used for real-time or near real-time monitoring with birds eye view. We evaluated imagery from LSA and UAV platforms for rapid change detection and reconnaissance of features potentially related to illegal smuggling activity (human and/or contraband) in the border region (Stow et al., 2008).

The SDSU project team completed assessed the accuracy of LIDAR and other digital terrain data (Intermap IFSAR, National Elevation Dataset, Shuttle Radar Topographic Mission, etc.). The LIDAR data were found to have an overall vertical root mean square error of 0.15 m (6 inch). The accuracy was assessed by land cover type, and this magnitude of error was consistent for all types evaluated except for chaparral vegetation, which had an error of 0.4 meters. The higher error for chaparral is attributed to the dense nature of its canopy, which likely does not allow LIDAR pulses to penetrate through to get a ground sample.

LIDAR data are appropriate for detailed terrain characterization. LIDAR and other terrain data were evaluated for their utility in creating high quality viewshed products (Kaiser and Coulter, 2007). The objective of the border viewshed assessment was to assist the Border Patrol in selecting the most suitable digital elevation model for use in the selection of border observation locations providing the greatest border visibility. The ability to observe all areas of the tactical border enforcement (containment) zone adjacent to the border is essential for effective Border Patrol interdiction and apprehension efforts. Areas lacking observation provide concealed pathways for cross border travel. Identification of optimal observation locations allows placement of agents to either increase their visibility as a deterrent to would be border crossers

or to provide concealment to prevent border crossers from knowing agent locations and taking evasive actions. Proper placement of Border Patrol observers enhances search and monitoring efforts while reducing costs and increasing the probability of successful interdictions.

The team evaluated the utility of LIDAR data for vegetation height, density, and structure characterization and measurement (Coulter and Stow, 2007). This information is useful for border security trafficability, fire risk and fire evacuation route studies. The team also tested LIDAR-derived products for improving multispectral image-based classification of vegetation fire risk using LIDAR data with 1.5 m post spacing provided. Three raster products were derived from the point data, which provided information of vegetation height and density (within canopy biomass). Unsupervised image classifications were generated using the LIDAR products alone, ADS40 multispectral imagery alone, and a composite image with ADS40 and LIDAR data. Accuracy was highest (84%) when LIDAR and ADS40 multispectral imagery were both utilized, providing spectral and structural information about vegetation. The accuracy of LIDAR alone and ADS40 alone was 70% and 77%, respectively.

2.1.2 Outcome Document: Monitoring Cross-border Trails Using Airborne Digital Multispectral Imagery and Interactive Image Analysis Techniques

Citation:

Cao, L., Stow, D., Kaiser, J. and Coulter, L., 2007. Monitoring Cross-border Trails Using Airborne Digital Multispectral Imagery and Interactive Image Analysis Techniques, *Geocarto International*, 22(2): 107-125.

PDF Document

Cao_et_al_2007_Monitoring_cross_border_trails.pdf

Abstract

The objective of this study was to evaluate image-based procedures for monitoring cross-border foot trails in the US–Mexico border zone in eastern San Diego County using airborne remote sensing techniques. Specifically, digital multi-spectral and multi-temporal imagery from an airborne digital multi-spectral imaging system, digital image processing, and visual image analysis techniques were explored in the context of detecting and delineating new trail features and updating trail GIS layers. Three trail updating approaches: map-to-image (M-I) overlay, map and image-to-image (M/I-I) differencing, map and image-to-image (M/I-I) swiping and two types of spectral transform, PCA and NDVI, were tested and compared. The M-I overlay was found to be the most reliable trail updating approach. The optimal image enhancement method for the M-I overlay approach varied with vegetation structure. PCA imagery yielded better results than NDVI imagery in a highly disturbed area and NDVI imagery performed better in a densely vegetated area. The M/I-I swiping approach was useful for distinguishing misregistered extant trails from new trail features.

Conclusions

The objective of this study was to develop and test image-based approaches and procedures for updating maps of trails associated with smuggling and immigration, for a portion of the US–Mexico border in San Diego County. Digital airborne multitemporal and multispectral ADAR imagery having nominal spatial resolution of 0.6 m was utilized as the image data source.

Three map-updating approaches (M-I overlay, M/I-I image differencing, M/I-I swiping) and two types of spectral enhancement image (PCA and NDVI) were tested and compared. The M-I overlay approach yielded over 40% more total new trail length than did the M/I-I image differencing approach, indicating that it was most sensitive to detecting new trails. Also, the M-I overlay approach was more reliable for updating than M/I-I image differencing, since it directly uses enhanced t=2 imagery rather than a difference image, which can contain the effects of misregistration and differential sun angles and vegetation seasonality between image dates.

For the M-I overlay trail maps, the results suggest that PCA and NDVI transformation yielded similar total delineated trail lengths, but their effectiveness for enhancing trail features depended on target (trail) to background (vegetation and rock outcrops) conditions. For disturbed areas where the trail networks were extensive, the PCA image was more effective at enhancing new trails. For densely vegetated areas, the NDVI image yielded more interpreted trails. Generally, the PCA image tended to highlight the center-line of the trails, while the color sliced NDVI image exaggerated the widths of the trails.

The M/I-I image differencing approach was less effective than the M-I overlay procedure. The use of the color PCA difference image resulted in 21% more total new trail length than did the NDVI difference image, indicating that the PCA difference image is superior to the NDVI difference image for the M/I-I approach.

The M/I-I swiping approach was found to be operationally difficult to implement due to difficulties in dealing with multiple image layers at one time. Upon testing this approach, results showed that: (1) newly formed (Type A) trails accounted for less than 5% of the total length of the delineated new trails; (2) trails that were shown more clearly on t=2 imagery than t¼1 imagery but were not detected in the baseline mapping phase (Type B) accounted for 30–40% of the total length of the delineated new trails; and (3) trails that were simply omitted in the baseline mapping (Type B') accounted for about 60% of the total length of the delineated new trails. An advantage of the M/I-I swiping approach is that it enables misregistered extant trails to be distinguished from new trail features.

High quality, well registered, and radiometrically matched multi-temporal image datasets greatly improve the efficiency and reliability of trail map updating procedures. In this study, a semi-automated image registration approach was used that incorporated a second-order polynomial warping function. In theory, a true rubber sheeting warping function can produce very tight registration when there is a sufficient number of ground control points (GCPs). Thus, true rubber sheeting warping functions should be tested, assuming that a large number of reliable GCPs can be generated automatically. Also, a frame centre matching approach to image acquisition and registration would be highly advantageous (Coulter et al. 2003). The radiometric differences

between ADAR image frames should be balanced or radiometrically normalized so that spectral-radiometric characteristics do not vary across the scene. Multi-temporal imagery should be radiometrically matched to reduce seasonal variability although absolute radiometric correction is not necessary.

Image acquisition timed for summer anniversary dates should be desirable for trail mapping and updating of the Mediterranean shrublands of the San Diego border zone. This should reduce artifacts of change resulting from differences in vegetation seasonality and sun angles, and trails will be more exposed and detectable on the imagery. With up-to-date trail maps, law enforcement officers can combine other GIS data such as terrain and vegetation density to identify 'hotspots' of crossing paths and predict where smugglers are likely to operate. These officers can then intercept smugglers at preferred locations rather than follow their footprints, which is very labor intensive and dangerous.

2.1.3 Outcome Document: Assessment of Commercial High Spatial Resolution Imagery for Border Monitoring

Citation

Coulter, L., D. Stow, M. Rosa, S. Lathrop, and T. Dougherty. 2009. Assessment of Commercial High Spatial Resolution Imagery for Border Monitoring. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document

Hres_Image_Assessment_Report.pdf

Executive Summary

The United States Customs and Border Protection agency is responsible for securing and guarding the nations borders, safeguarding the American homeland against terrorism, and enforcing the laws of the United States. Remote sensing offers the potential to monitor expansive areas within the border region and determine if there are illegal transient/smuggling routes that have not been detected by agents patrolling the border. The purpose of the assessment of commercial high spatial resolution imagery is to determine the types and sources of imagery that will efficiently provide the appropriate information to support the USBP in their work/mission.

Satellite and airborne image sources were reviewed. However, two separate studies performed as part of this REASoN project found that high spatial resolution satellite imagery with 0.6 m spatial resolution is too coarse for effectively mapping trails on single date imagery or for detecting trail changes using multitemporal imagery. Therefore, the assessment of high spatial resolution imagery focused on commercial airborne imaging systems.

Commercial large format digital camera (LFDC) systems have been utilized for airborne collection of multispectral imagery since 2001. These systems include the Leica Geosystems ADS40, the Intergraph Z/I Imaging® DMC, and the Vexcel UltraCam. LFDC systems collect

imagery with detail comparable to large format film while yielding finer radiometric resolution and greater spectral coverage than film. Characteristics of LFDC systems were reviewed and compared.

Companies operating LFDC systems in the United States were surveyed in April 2006 to obtain general information on technical specifications and costs of image products derived from their large format digital sensor systems. Six vendors responded to the survey and three of those provided custom demonstration data sets for evaluation. Information such as daily productivity, cost of image products and associated turn-around time, system configuration and perceived advantages was gathered from each vendor that participated in the survey. Demonstration data sets from the three camera systems were utilized to assess general image product characteristics; spatial spectral, and radiometric quality; effects of pansharpening on quantitative analyses; and the accuracy of multitemporal spatial co-registration for change detection.

Conclusions

The ADS40, DMC, and UltraCam large format digital camera systems represent the state of the art for airborne image collection and high spatial resolution imagery. All of these sensors are capable of collecting high quality imagery for a variety of purposes. Each of these sensors collects digital imagery with 12-bit or greater radiometric range using charge coupled device (CCD) technology. Further, for the detection of detailed changes along the border, each image type was found to be able to achieve high spatial co-registration accuracy.

Results from this study suggest that Z/I Imaging's DMC camera is most appropriate sensor for performing detailed change detection in the context of monitoring the U.S. international land borders. The DMC was found to yield the lowest cost imagery, a high daily productivity rate, and the best spatial acuity resulting in sharp images for feature and change detection. Further, the DMC can utilize LIDAR (or other high quality terrain models), GPS, and/or IMU data for controlling image orthorectification, but does not require these data to enable detailed change detection as the ADS40 does. DMC imagery is pansharpened, however there is no evidence that pansharpening reduces the utility of the imagery for change detection.

It should be noted that UltraCamX and UltraCamXp sensors were largely not evaluated for this report, and results could be different if these newer sensors with wider fields of view were included for all aspects of the image assessment (survey, demonstration data evaluation, etc.). Further, the UltraCam systems are similar to the DMC system in most respects (2-dimensional array, pansharpened imagery, optional GPS/IMU, etc.).

The ADS40 demonstration image set was a free product provided by the vendor that was not fully acquired to usual production specifications and it is possible that another ADS40 or ADS80 image set might not yield difference image artifacts such as those identified within the demonstration image set. Therefore, these systems should be considered for future testing and evaluation. If it is again found that there are problems with multitemporal difference images, then it may be that ADS40 imagery should only be used for single date remote sensing purposes (i.e., semi-automated image classification, etc.) and not for pixel-level change detection. Results and published information suggest that the ADS40 SH40 sensor head yields imagery with

waveband and multitemporal image co-registration artifacts due to the differing view angles of the cir wavebands. The ADS40 SH51 and SH52 sensor heads and the ADS80 SH81 and SH82 sensor heads all have multispectral wavebands viewing from the same perspective and do not have the co-registration issues of the ADS40 SH40 sensor.

2.1.4 Outcome Document: Detailed Change Detection Using High Spatial Resolution Frame Center Matched Aerial Photography

Citation:

Coulter, L., Lathrop, S. and Stow, D. 2005. Detailed Change Detection Using High Spatial Resolution Frame Center Matched Aerial Photography. *20th Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, October 2005, Weslaco, TX.

PDF Document

Coulter_2005_ASPRS_FC_Change_Detection.pdf

Abstract

Advances in computer and digital imaging technology have enabled the geospatial community to remotely view and analyze land cover and changes in land cover at very high detail. This paper explores the application of detailed change detection using precisely-registered, multitemporal digital aerial photographs. Six inch (0.15 m) spatial resolution color infrared aerial photographs were acquired along the San Diego County section of the U.S./Mexico border in May 2004 and July 2005. A technique referred to as frame center matching was employed during the flight, which enabled precise registration of the multitemporal image frames. Independent check points indicate that a registration root mean square error of 0.49 ft (0.15 m) was achieved. Multitemporal image overlay techniques were used to detect land cover changes associated with fire, development, illegal immigration, and border protection activity. The techniques presented enable the detection of fine-scale land cover changes for resource management.

Conclusions

Monitoring natural resources through image-based change detection requires precise registration between multitemporal imagery. The frame center matching approach to image acquisition and registration enabled accurate registration of very high resolution, multitemporal images in a area along the U.S./Mexico border with mountainous terrain. A simple change detection approach using color overlay composites illustrated the utility of precisely registered, multitemporal imagery for detecting detailed, small area land cover changes germane to natural resources management and monitoring. Land cover changes occurring on a scale of less than one meter were detected.

While a simple change detection procedure was employed here for demonstrative purposes, advanced image processing procedures are required to create a change map using multitemporal aerial photography. These include radiometric corrections for effects such as vignetting, hot

spots, and solar illumination difference, and radiometric normalization of brightness values between dates. In addition, advanced image classification procedures exploiting the multispectral nature of color infrared imagery are necessary to categorize the types of changes occurring. These may include classification and post-classification comparison, change vector analysis, multidate classification, and multitemporal spectral mixture analysis.

2.1.5 Outcome Document: Classifying Vegetation Fire Fuels using Multispectral Imagery and LIDAR-derived Vegetation Height and Density

Citation:

Coulter, L. and D. Stow. 2007. Classifying Vegetation Fire Fuels using Multispectral Imagery and LIDAR-derived Vegetation Height and Density. *21st Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, May 2007, Terre Haute, IN.

PDF Document

Coulter_2007_ASPRS_LIDAR_Classification.pdf

Abstract

Light detection and ranging (LIDAR) data are often collected in conjunction with multispectral imagery and aerial photography. LIDAR data have primarily been used to create terrain products for topographic modeling and image orthorectification. However, LIDAR data may also be exploited to derive information on vegetation height, density, and structure. This study explores the utility of LIDAR-derived vegetation height and density products for improving multispectral image-based classification of vegetation fire fuels within canyons of the City of San Diego. Five classes of vegetation fire risk defined by a Wildland Fire Risk/Hazard Severity Assessment model developed by the San Diego Fire-Rescue Department are analyzed, which range from bare soil to tall, dense shrubs and trees. It is demonstrated that classification accuracy is substantially improved when LIDAR-derived products and visible/near-infrared (V/NIR) multispectral imagery are used, compared to classification based on V/NIR multispectral imagery alone. The techniques presented for LIDAR-based vegetation characterization and combined classification with multispectral imagery are broadly applicable to resource management.

Conclusions

LIDAR data are increasingly available and collected in conjunction with high resolution multispectral airborne imagery. Classification of land cover types (such as vegetation) with unique height and/or density characteristics can be aided and improved using LIDAR data and/or derived products. The accuracy with which vegetation fire fuels were classified within the City of San Diego study site was substantially improved when LIDAR-derived products were used in conjunction with multispectral imagery, compared to the accuracy obtained using only multispectral imagery. While the LIDAR-derived products did not improve classification of high risk vegetation, it did aid discrimination of low risk vegetation and land cover. The

LIDAR-derived products alone contained sufficient information to classify vegetation fire fuels with moderate accuracy.

2.1.6 Outcome Document: Assessment of the Spatial Co-registration of Multitemporal Imagery from Large Format Digital Cameras in the Context of Detailed Change Detection

Citation:

Coulter, L. and D. Stow. 2008. Assessment of the Spatial Co-registration of Multitemporal Imagery from Large Format Digital Cameras in the Context of Detailed Change Detection. *Sensors*, 8:2161-2173. .

PDF Document

Coulter_2008_RS_Sensors_Special_Issue.pdf

Abstract

Large format digital camera (LFDC) systems are becoming more broadly available and regularly collect image data over large areas. Spectral and radiometric attributes of imagery from LFDC systems make this type of image data appropriate for semi-automated change detection. However, achieving accurate spatial co-registration between multitemporal image sets is necessary for semi-automated change detection. This study investigates the accuracy of co-registration between multitemporal image sets acquired using the Leica Geosystems ADS40, Intergraph Z/I Imaging® DMC, and Vexcel UltraCam-D sensors in areas of gentle, moderate, and extreme terrain relief. Custom image sets were collected and orthorectified by imagery vendors, with guidance from the authors. Results indicate that imagery acquired by vendors operating LFDC systems may be co-registered with pixel or sub-pixel level accuracy, even for environments with high terrain relief. Specific image acquisition and processing procedures facilitating this level of co-registration are discussed.

Conclusions

Multitemporal imagery acquired and processed by vendors operating large format digital camera systems may be co-registered with near-pixel level or sub-pixel level accuracy, even in environments with high terrain relief. Once accurate co-registration is achieved, such high spatial resolution, multitemporal image sets can be utilized for semi-automated change analysis and detection of fine scale changes.

Co-registration accuracy will depend upon image acquisition and/or image preprocessing techniques. For this study, imagery from frame array sensors (i.e., DMC and UltraCam) was acquired with matched frame centers, and imagery from a line array sensor (i.e., ADS40) was acquired by repeating the same flight line (and same altitude) on multitemporal imaging passes. These methods of image data collection are recommended when accurate co-registration of multitemporal image sets is desired.

Results from this study suggest that achieving pixel-level co-registration with frame center matched frame imagery or flight line matched line array imagery requires at least: 1) accurate horizontal and vertical control for aerotriangulation and a consistent digital terrain model for orthorectification of each image set or 2) frame-to-frame co-registration of FC matched frame imagery. Incorporation of high quality digital terrain data for image orthorectification will provide the best results, but can be a more expensive solution. Accurate horizontal and vertical control may be generated with GPS/IMU or ground control points.

2.1.7 Outcome Document: Evaluation of Remote Sensing Technologies for Mapping Trans-border Trails

Citation:

Kaiser, J., Stow, D., Cao, L. and Coulter, L. 2004. Evaluation of Remote Sensing Technologies for Mapping Trans-border Trails. *Photogrammetric Engineering & Remote Sensing*, 70 (12): 1441-1447.

PDF Document
Kaiser_et_al_2004_trail_mapping.pdf

Abstract
This paper evaluates the utility of various image processing methods for mapping smuggler trail networks crossing the U.S.-Mexico border. Very high spatial-resolution, digital, multispectral imagery was acquired in three visible and one nearinfrared wavelength bands along the U.S.-Mexico border using an Airborne Data Acquisition and Registration (ADAR) digital camera system mounted on a helicopter. Four image enhancement methods and one neural-network based automated feature extraction technique were tested. Measures of trail length were compared with a ground-based GPS trail survey to evaluate accuracy.

The optimal image enhancement method for trail mapping varied with topography and vegetation structure. The green vegetation component from spectral mixture analysis (SMA) and the normalized difference vegetation index (NDVI) were most useful for enhancing trails for subsequent interactive visual interpretation and digitizing. The neural network feature extraction technique produced superior results when combined with interactive digitizing.

Conclusions
The use of enhanced, high-spatial resolution imagery appears to be a cost effective approach to meeting border agency needs to maintain current trail maps along the southern California border with Mexico. Five primary conclusions can be drawn from this study, which are stated as follows:

(1) Helicopters are effective platforms for very high-resolution imaging in terrain with rapidly varying elevation, as they enable adjustments in along-track flight altitude, between image capture stations, to maintain nearly constant image scale.

(2) Digital multispectral camera systems provide image data having very high spatial resolution and sufficient spectral-radiometric fidelity, in a flexible manner, such that most trail features can be detected and digitally mapped.

(3) Spectral mixture analysis, which apparently has not been tested for linear feature extraction based on high spatial resolution imagery, proved to be the most effective enhancement or transform approach that was tested.

(4) The most effective and efficient approach to trail mapping was a hybrid of an automated linear feature extraction routine, followed by manual interpretation, delineation, and editing; this approach yielded a 73 percent increase in mapped trail length and the highest overall accuracy results.

(5) Given the difficulties and uncertainties in validating trail maps derived from very high spatial resolution image sources for areas of irregular relief, use of GPS surveys for a sample of trails, total delineated trail length as an accuracy metric, and application of the epsilon envelope concept seem to be reasonable means towards assessing accuracy

2.1.8 Outcome Document: Digital Elevation Model Assessment for Border Viewshed Analysis

Citation:

Kaiser, J. and L. Coulter. 2007. Digital Elevation Model Assessment for Border Viewshed Analysis. REASoN project report, Department of Geography, San Diego State University.

PDF Document

Viewshed Final Report 12 March 2007.pdf

Abstract

Protecting America's international borders has become a high priority since the terrorist attacks of 11 September, 2001. Large portions of America's southern border are remote and sparsely populated and as a result are extensively used to smuggle people and contraband. It is estimated that 3,500 illegal immigrants enter the United States every day along the southern border, a rate of two illegal entries per minute (Spagat, 2006). Crossing the U.S. southern border with Mexico on foot remains the principal method of entering the United States illegally for those who cannot otherwise gain entry using student, work or tourist visas (Berestein, 2006).

Interdiction and apprehension of illegal immigrants at the border is a vital component of the United State Border Partol's (USBP) national strategy of defending our nation's borders. The area in immediate proximity of the U.S.-Mexico border is the principal region of border enforcement and illegal crosser containment. Early detection by border agents of illegal crossers,

knowing where, in what direction and how fast they are traveling is essential information to conducting safe and successful apprehensions.

This study compared the vertical accuracy and derived viewshed extent for five digital elevation models (DEM) having horizontal postings ranging from 1.5 m (5 feet) to 30 m (100 ft). The DEMs were derived from National Elevation Dataset (NED), U.S.G.S. topographic maps, airborne IFSAR radar and airborne LIDAR sources. Viewsheds were compared against each other and to a reference surface of high density elevation points collected using survey-grade Global Positioning System (GPS) equipment. Results were used to determine the most suitable DEM for border viewshed creation considering availability, accuracy and cost. A border study area and a separate City of San Diego area were used for DEM evaluations.

Results suggest that high sampling density LIDAR and IFSAR DEMs provide the highest vertical accuracy and viewshed results in terms of terrain representation and vertical accuracy. Less costly NED 30 m and 10 m data provide suitable results where identification of blind spots (hidden pathways) is not critical.

Conclusions

Knowing which type of DEM is most reliable and accurate is of major importance to the USBP for viewshed analyses. The ability to obtain realistic and accurate viewsheds is essential to a variety of planning and operational activities. The selection and implementation of observation sites to monitor border viewsheds and the activity within them requires accurate viewshed analyses. Knowing what can be seen from where aides significantly in interpreting and understanding cross border trail patterns and smuggler activities. Operational planning benefits from reliable viewshed information.

The key to all viewshed analyses is an accurate and reliable digital elevation model (DEM). Two of the most critical characteristics of a DEM are the spatial resolution of the sample spacing (posting distance) and vertical and horizontal location accuracy. The presence or absence of artifacts is another import consideration.

Higher spatial resolution DEMs appear to have more accurate elevation values and represent surface terrain better. LIDAR DEMs were found to have the highest vertical accuracy and smallest posting (highest spatial resolution) distances. LIDAR is however, not readily available for most border regions and is currently more costly to produce than other DEMs. In addition, special software is required for processing the very large data sets associated with LIDAR images and their derived DEMs. Fortunately, both the cost and availability of LIDAR data are improving and LIDAR data processing is being incorporated in more GIS and image processing programs.

IFSAR DEMs provide vertical accuracy close to that obtained from LIDAR, with data sets more widely available and at lesser cost than LIDAR. The NOAA IFSAR 3 m data and Intermap IFSAR 5 m DEMs provide realistic viewsheds with acceptable accuracy. Significantly, IFSAR data are widely available both commercially and from government agencies at reasonable cost.

NED DEMs at the 10 m and 30 m scales are least accurate vertically. However, they are widely available from commercial and government sources and minimum cost.

For border regions similar to the Tecate study site, and considering availability, cost and quality of viewshed produced, the Digital Elevation Models are listed in order from most suitable to least suitable:

NOAA IFSAR 3 m DEM
InterMap IFSAR 5 m DEM
LIDAR 1.5 m DEM
SANDAG 10 m DEM
NED 30 m DEM

Successful application of viewshed analyses will allow the Border Patrol to evaluate current observation locations and to make location adjustments to improve Border surveillance at other border locations. Selection of the most suitable DEM will enhance the quality and confidence in the resulting viewsheds.

2.1.9 Outcome Document: Updating Maps of Foot Trail Networks for the US-Mexico Border Zone Using Semi-automatic Feature Extraction Methods and Very High Resolution Remotely Sensed Imagery

Citation:

Lathrop, S. 2009. Updating Maps of Foot Trail Networks for the US-Mexico Border Zone Using Semi-automatic Feature Extraction Methods and Very High Resolution Remotely Sensed Imagery. Master's thesis. San Diego State University.

Lathrop, S., Stow, D., Coulter, L. and Hope, A. Manuscript in final stage of preparation. Updating Maps of Foot Trail Networks for the US-Mexico Border Zone Using Semi-automatic Feature Extraction Methods and Very High Resolution Remotely Sensed Imagery.

PDF Documents

Not available, documents in press and preparation.

Abstract

A consequence of the U.S. Border Patrol initiative "Operation Gatekeeper" has been the development of a complex, dynamic foot trail network in remote areas in the US-Mexico border zone of eastern San Diego County. The ability to comprehensively monitor changes in trail networks depends on the timely production of accurate, up-to-date trail maps from remotely sensed imagery. In this study three semi-automated, commercially available object extraction routines were evaluated for delineating new trails. The routines that were tested included a per-pixel spatial-spectral classifier which uses an artificial neural network (ANN) approach to object

extraction, an object-based routine which uses image segmentation and a nearest neighbor classifier, and a spatial filtering algorithmic approach which is based on an edge enhancement and buffering technique to extract new trail objects. Input imagery consisted of three types of multi-temporal difference images or layerstacks generated from two dates of scanned color infrared (CIR) multi-spectral images of the US-Mexico border study sites: (1) difference images for three (green, red, and near infrared) multi-spectral wavebands, (2) red-band only multi-temporal layerstack, and (3) Normalized Difference Vegetation Index (NDVI) difference images. Input imagery at 15, 30, 60, and 120 cm spatial resolution was tested to determine the optimal spatial resolution for each semi-automated feature extraction method. Accuracy was assessed using a "new trail" reference map created by two skilled image interpreters. This allowed for a quantitative measure of agreement and commission error for each product based on a novel approach to comparing extracted and reference trails. The new trail maps produced by the semi-automated routines generally delineated those trails that were well-defined, spectrally uniform, and free of obstruction. Feature Analyst and Definiens products had high agreement relative to commission error, with the best results generally derived with the 15 and 30 cm resolution imagery. Feature Analyst, with a built-in hierarchical learning process, was able to reduce overall commission error, resulting in products that could be used effectively by image analysts to complete the updating of trail maps. CIR difference and red-band multi-temporal layerstack images consistently outperformed NDVI difference images in correctly extracting new trails.

Conclusion

The use of existing semi-automated feature extraction methods may assist image analysts in delineating new foot-trails in multi-temporal imagery, but are not sufficiently reliable or automated to eliminate the need for analyst interaction. The routines used in this study can save on time and effort required by image analysts. With further advances in object-based image analysis and post-processing routines, the need for manual interpretation and editing may be diminished substantially, but it is doubtful that the need will be eliminated.

Agreement vs. commission error results for both study sites demonstrated that CIR and RBL inputs using 15 and 30 cm spatial resolution imagery generally outperformed all other inputs and resolutions at correctly extracting new trail objects and reducing commission error. Feature Analyst and Definiens outperformed the Spatial Modeler routine in reducing commission errors.

Of the three semi-automated feature extraction routines used for this study, Feature Analyst is the easiest to use, and has the shortest learning curve. Additionally, Feature Analyst offers a hierarchical learning and post-processing work flow that enables reduction of commission errors and produce results superior to the DE and SM versions that were tested.

CIR and RBL inputs produced similar results in this study, suggesting that soil to vegetation contrast is greatest in the red waveband, and/or highly correlated in green, red, and NIR wavebands. With just two bands, processing of the RBL image was faster than CIR, which can be an important consideration when processing large areas.

The higher spatial resolution input imagery (< 30 cm) yielded new trail products with higher accuracy and lower commission errors than lower resolution (>60 cm). This suggests that

airborne image data are required to reliably delineate new trails, though some satellite sensing system are beginning to achieve spatial resolutions less than 60 cm.

The semi-automated routines used in this study relied heavily upon consistent rules and characteristics when extracting features of interest. The three routines that were tested have been used with success for road extraction, but have difficulty with trails due to varying width, composition and shape, and lack of sharp, contrasting edges.

The resultant new trail products may have value when used in conjunction with visual, "heads-up" delineation. Cao et al. (2007) used a map-to-image swipe technique that can be used manually to join new-trail segments and to eliminate false positives in a manual process employing remote sensing software data layer flicker, swipe, and vector digitization capabilities. A map or GIS layer depicting pre-existing trail networks may assist an image analyst in successfully delineating new trails. Some steps can be taken to increase the value of the products by reducing the amount of input imagery in the semi-automated routines. Stratification based on classification and/or masking can be useful in reducing computational requirements and enabling specialized or tailored extraction routines to operate on smaller areas. Past studies have employed masking techniques to eliminate areas where a specific target can not be present (Youn et al. 2008), which may help to reduce commission error if applied to future studies of trail networks. For example, areas containing slopes that are too steep to be traversed, large bare soil or rocky areas, dense vegetation, or roads can be eliminated or masked from the study in its initial stages, either manually or via a GIS-based model based on vegetation, substrate, or terrain maps or GIS layers. Lu et al. (2007) found that preprocessing using NDVI to separate vegetated and non-vegetated areas allowed removal or masking of areas where target features did not exist, and led to improved extraction accuracy.

Future attempts to delineate new trail objects may benefit from the use of iterative hierarchical grouping approaches, such as those used by Hu and Tao (2007) to link extracted fragments of straight-line and curved road segments. The use of geometric and radiometric characteristics of the line segments, as well as proximity of fragments to pre-classified longer linear segments could be used as a post-processing tool to automate the process of forming a more complete new trail map, while reducing the amount of operator interaction required.

The use of LSB snakes (Kass 1988, Gruen & Li 1997), which are able to find the path of least spectral resistance between nearby extraction vectors, in conjunction with feature extraction methods may allow for further reduction of commission error, while increasing the connectivity of extracted new trails. Future study should include methods to connect disparate line segments, such as the RoadTracker tool from Overwatch Systems, which uses a proprietary process similar to LSB snakes.

2.1.10 Outcome Document: Remote Sensing and Image Processing (RS/IP): An Important Component of a Target Mapping System.

Citation:

Stow, D., L. Coulter, C. Lippitt, M. Rosa, Y. Hamada, M. Caldwell, J. Nunley, T. Tidwell, and R. McCreight. 2008. Remote Sensing and Image Processing (RS/IP): An Important Component of a Target Mapping System. Project report for the Office of National Drug Control Policy, Department of Geography, San Diego State University.

PDF Document

ONDCP_RSIP_Final_Report.pdf

Executive Summary

Remote sensing may be utilized to locate drug transportation infrastructure along the United States International borders, and ultimately disrupt networks and influence national policy. The goal of the remote sensing and image processing component of the target mapping system is to demonstrate the capability of airborne imaging systems and image processing to provide practical methods with which law enforcement may efficiently and effectively locate drug-related infrastructure. The National Geospatial-Intelligence Agency (NGA) is leading an effort to collect current (2008/2009) high spatial resolution imagery for all of the United States international land borders and make it publicly available. This image set provides a baseline against which future land cover changes may be assessed.

Illegal trans-border infrastructural features such as tunnels, trails, structures and spoil piles are expected to impact local land cover and yield evidence (or signatures) that may be used to detect the activity. Multitemporal imagery from large, medium, and/or small format sensors may be utilized to detect land cover change relative to the NGA baseline image set and also to provide ultra high spatial resolution imagery for reconnaissance of detected features of interest. We demonstrate this scenario using large format Z/I Imaging DMC imagery (similar to that which will be collected by NGA) and low-cost medium and small format imagery from light sport aircraft (LSA) and unpiloted aerial vehicles (UAVs). Change detection analysis highlighted several features of interest, and ultra-high spatial resolution imagery was collected to provide additional information for some of these features of interest.

In addition to demonstrating the change detection and reconnaissance scenario, we investigated methods for minimizing preprocessing and evaluated several semi-automated approaches for detecting trans-border features of interest such as new trails, soil disturbance, and new buildings, which may be associated with illegal activity.

Conclusions

Remote sensing and image processing capabilities provide unique intelligence relating to illegal trans-border activity that may be associated with drug trafficking into the United States. The high spatial resolution image set soon to be available for the full extent of U.S. international land borders will serve as a valuable baseline image set against which future land cover changes may

be assessed. For change detection and reconnaissance, current (at the time of collection) imagery may be acquired by commercial vendors or acquired using low cost and flexible platforms and sensors that are available commercially off-the-shelf.

We demonstrated that systems such as the NEOS light sport aircraft and LOUIS unpiloted aerial vehicle may be used to collect imagery, create mosaics, perform change detection, and collect ultra-high spatial resolution imagery within hours for rapid intelligence and reporting purposes. Figure 40 illustrates how our team completed an image collection and prepared imagery for near real-time change detection in the field.

Methods for efficient change detection were evaluated and reviewed. These methods may be implemented by novice analyst with minimal training.

2.2 Moderate Spatial Resolution Remote Sensing

The utility of Landsat TM/ETM data for detecting changes in natural ecosystem condition along the US-Mexico border arising from human traffic and interdiction activities was examined. The goal was to determine if documented increases in immigrant traffic during the 1991-2005 period have resulted in impacts on the environment which can be detected using Landsat imagery. The environmental effects from foot traffic and interdiction activities along the San Diego Sector of the border remain an item of strong interest to the Border Patrol and environmental agencies.

2.2.1 Key Accomplishments

Results from initial REASoN project analyses indicate that the effect of trails and immigrant traffic on vegetation density and condition does not appear to be detectable or quantifiable using standard image differencing change detection techniques with Landsat TM satellite imagery. The dominant vegetation change signals are associated with large-scale disturbances associated with fires and seasonal variation in vegetation condition. The team assessed the relationship between new trail length and red waveband difference and normalized difference vegetation index (NDVI) difference for a small study area known to have a considerable increase in the number and size of trails between 2002 and 2005. New trail lengths were determined using very high spatial resolution (< 1 m) imagery. This site is characterized as grassland, with no significant disturbances from 2002 to 2005 (other than new trails). Results from several analyses with Fall 2002 and Fall 2005 Landsat TM imagery (aggregated to 90 m spatial resolution to reduce effects of misregistration on change detection) suggest that seasonal variation in the dry grassland is the dominant change signal, and that there is no relationship between red waveband spectral difference or NDVI difference and trail length change. Trail length increases up to 5700 feet (1738 m) were observed within the ground extent of individual 90 m^2 Landsat TM pixels, but these trail changes did not correlate with spectral-based differences.

The bottom-up change detection technique described above (looking at a small area of known change) did not reveal any cause and effect relationship between disturbance associated with immigrant traffic and spectral-based change. This is likely due to the dynamic variation in

vegetation condition that is associated with fire and seasonal vegetation changes. This dynamic variation results in change detection "noise" that is higher than the signal of vegetation change associated with immigrant traffic.

The project team assessed a novel spectral-temporal method for normalizing imagery and resulting change products for dynamic variations associated with localized seasonal vegetation changes. The method was expected to minimize the change detection "noise" associated with natural vegetation variation and enhance lower magnitude land cover changes of interest within the border region (such as vegetation degradation due to immigrant traffic or other human disturbances).

The method employs a time series of Landsat TM NDVI images (aggregated to 90 m spatial resolution to reduce effects of misregistration on change detection) for Fall 1991, 1996, 1999, and 2002 to identify units within the landscape that behave similarly over an eleven year period. These individual units (or spectral-temporal strata) are not necessarily contiguous but contain similar vegetation types with consistent seasonal variations, and similar fire history. Normalization on a per-unit basis was expected to suppress variations in spectral response associated natural vegetation change (phenology, fire recovery, vegetation growth, etc.). Utilizing the stratified relative radiometric normalization technique, the team normalized images and derived products (e.g., NDVI) for a 2002-2005 change period of interest individually for stratum and assessed the results.

2.2.2 Outcome Document:

Citation
Coulter, L., Hope, A., Lippitt, and Stow, D. Detecting Landscape Disturbance Along the US-Mexico Border Using Thematic Mapper Time-series Data. *Photogrammetric Engineering and Remote Sensing*. Planned submission November 2009.

PDF Document
Coulter_2009_Strat_Rel_Rad_Norm.pdf

Introduction and Objectives
Digital change detection using remotely sensed imagery facilitates mapping of land cover changes occurring over large areas. Multitemporal imagery utilized for change detection must be spatially and radiometrically aligned so that a change in brightness between corresponding pixels indicates a change in surface condition (Lu et al., 2004, Coppin et al., 2004). The goal of change detection is often to identify human-induced land cover changes.

Lambin and Strahler (1994) list five general causes of land cover change: human-induced disturbance, erosion and vegetation succession, weather and plant phenology, climate, and greenhouse effects. If detection of human-induced change using remote sensing is the goal, then the natural environmental changes, which affect the spectral reflectance properties of land cover

materials and may vary between multitemporal image sets must be controlled for. However, these changes occur at varying spatial and temporal scales according to landscape, vegetation type, season, and episodes of local disturbance (Lu et al., 2004; Jensen 1996; Weber 2001). These combined controls on land cover characteristics result in a patchwork of units or stands with varying timing and magnitude of reflectance. Therefore, controlling for localized reflectance variability over large areas is challenging.

The objective of this research is to evaluate a novel approach to image radiometric normalization for change detection which controls for localized spatial-temporal variability of natural land cover reflectance. Such a normalization approach would ideally increase detection of actual changes and reduce false detection of change resulting from natural or expected scene variability that is not of interest.

Conclusions

The reflectance of natural land cover materials varies over space and time due to such things as episodic disturbances and subsequent recovery, vegetation phenology, and long-term climate/environmental trends. Standard radiometric normalization procedures normalize images on a global basis but do not account for such localized variability. The SRRN procedure spatially stratifies the landscapes into units with similar pre-change period spectral-temporal history using a time series of imagery, then normalizes the change period images individually per stratified unit. The SRRN procedure effectively normalized localized spatial-temporal variability in natural land cover reflectance, where standard reflectance normalization of the imagery did not.

The SRRN procedure improved change classification accuracy, relative to a reflectance normalized image set when the magnitude of difference from zero was used as the basis of threshold-based classification. When a complete set of reference data (reference data for every pixel in the image) was used to calibrate the change classification of reflectance normalized imagery, the change classification accuracy was higher than the SRRN normalized change classification. These results suggest that some amount of noise may be added into the difference image change classification by the SRRN procedure.

The context of this research was change detection in the U.S./Mexico border zone of San Diego County. This is a dynamic area where land cover changes occur frequently due to fires, law enforcement activity, illegal immigrant activity, and natural fluctuations in vegetation associated with phenology and interannual weather patterns. The SRRN procedure was found to be effective for normalizing imagery in this environment. The SRRN procedure is expected to effectively normalize imagery in environments where localized patterns of disturbance, recovery, vegetation phenology, and/or long term changes in land cover reflectance results in a patchwork of units exhibiting localized variability in spectral-temporal reflectance.

2.3 GIS Analysis and Modeling

Several geospatial models and processing routines were created and evaluated, with the goal of providing the US Border Patrol tool sets that could be employed to improve human safety and interdiction success in the regions adjacent to the US/Mexico border. The individual models are described below.

Tunnel Location Prediction Model

The objective of the Tunnel Location Prediction Model is to identify areas astride the San Diego County-Mexico border that are suitable and likely to be exploited for the construction of clandestine transborder tunnels. The benefit of this research is the identification of areas having a high probability of tunnel exploitation allowing targeted deployment of high resolution, active detection sensors in a timely and cost effective manner. Many portions of the 106 km (66 mile) long San Diego Sector of the US-Mexico border are unsuitable for tunneling. Focusing search and monitoring activities in likely areas greatly reduces unproductive search areas, reduces costs and increases the probability of successful interdiction.

Clandestine Airfield Location Prediction Model

The clandestine airfield location prediction model is designed to assist in the prediction of clandestine airfield locations north of the U.S.-Mexico border through the combined use of remotely sensed imagery and GIS modeling. This research produced geospatial analysis tools for use by Border Patrol analysts to generate actionable intelligence for distribution and integration into in the Border Patrol SDSS.

Border Fire Risk Prediction Model

This fire risk predication model is designed to assist in the prediction of fire risk along the San Diego Sector of the U.S. Border. Its goal is to improve identification of fire risk to Border Patrol agents, border residents and immigrants in areas adjoining the San Diego Sector of the U.S.-Mexico Border. The predictive model combines the use of remotely sensed imagery and GIS modeling.

Border Climatic Risk Prediction Model

The Climatic Risk Model is designed to assist in the prediction of seasonal climatic hazards and risks to Border Patrol agents and immigrants astride the San Diego Sector of the U.S.-Mexico Border and within the sector's tactical enforcement zone. The goal is to provide the ability to produce timely weather and climate related risks maps for Border Patrol use.

The San Diego sector of the U.S.-Mexico border is approximately 106 km in length and traverses rapidly varying terrain and several climatic zones from a temperate coastline to snow covered mountains eastward to the scorching desert of the Imperial Valley. Seasonal variations transform the mountain and desert areas into high risk climatic zones with a history of climate related fatalities.

Border Viewshed Prediction Model
The objective of this viewshed analysis is to identify areas astride the San Diego County-Mexico border that are suitable as observation locations providing the greatest border visibility. The ability to observe all areas of the tactical border enforcement zone are essential to effective Border Patrol interdiction and apprehension efforts. Areas lacking observation provide concealed pathways for cross border travel. The identification of smuggler observation locations from which Border Patrol activities can be observed are of equal importance to effective border enforcement. Identification of optimal observation locations allows placement of agents for both optimal visibility (deterrent effects) as well as concealment (interdiction). Proper observer placement enhances search and monitoring activities greatly reducing costs and increasing the probability of successful interdictions.

Border Foot Trafficability Prediction Model
The Foot Trafficability Model is designed to assist in the prediction of foot traffic travel rates in areas immediately adjoining the San Diego Sector of the U.S.-Mexico border. The goal is to improve interdiction success rates by determining how rapidly individuals travel along specific smuggler routes and by improving the timing of the arrival of Border Patrol assets for apprehension. The project team is explored the use of image based technologies to extract synoptic land cover data for use in modeling cross border pedestrian trafficability. Slope, aspect, vegetation, roads and trails influenced the rate-of-travel parameters within the model. Traveling by foot is strongly influenced by the gradient of mountain slopes. Vegetation often acts as barriers to movement slowing or diverting foot traffic. Trails and roads act as passages through vegetation barriers, allowing faster travel rates, but also channeling foot traffic. Other effects such as weather, temperature and levels of illumination affect travel rates universally across wide areas.

Aircraft RADAR Fade Analysis
The aircraft radar fade analysis examines aircraft radar fades in conjunction with geospatial data and remotely sensed imagery to reveal patterns in aircraft smuggling activity useful for law enforcement countermeasures. This analysis is designed to produce geospatial analysis tools for use by Border Patrol analysts to generate actionable intelligence for distribution and integration into in the Border Patrol spatial decision support system.

2.3.1 Key Accomplishments

The GIS models have been provided to the Border Patrol and all except the border fire risk prediction model are planned for implementation and expected to be fully operational for the San Diego Sector of the Border Patrol (See section 3.0).

2.3.2 Outcome Document: Border Foot Trafficability Prediction Model

Citation

Kaiser, J., Stow, D., and Krall, D. 2007. Logic Model: Border Foot Trafficability Prediction Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document

Kaiser_and_Stow_2007_Foot_Trafficability.pdf

Abstract

Protecting America's international borders has become a high priority since the terrorist attacks of 11 September, 2001. Operation Gatekeeper and other border security initiatives since the 2001 terrorist attacks made it more difficult for individuals to enter into the U.S. prompting illegal immigrants to hire smugglers to help them cross into the U.S. from Mexico (Soto, 2006). Crossing the U.S.-Mexico border with on foot remains the principal method of entering the U.S. illegally for those who cannot otherwise gain entry using student, work or tourist visas (Berestein, 2006). Large portions of America's southern border are remote and sparsely populated and as a result are extensively used to smuggle people and contraband. Even with such increased border enforcement, it is estimated that 3,500 illegal immigrants enter the U.S. every day along the southern border, a rate of two illegal entries per minute (Spagat, 2006).

The area in immediate proximity of the U.S.-Mexico border is the principal region of border enforcement. Detection by border agents or security sensors of illegal crossers initiates interdiction and apprehension activities. Knowing where, in what direction and how fast illegal immigrants are moving become essential information elements in conducting successful apprehensions.

The goal of the this study is to predict rates of pedestrian travel and distance/travel-time horizons along selected portions of the San Diego Sector of the U.S.-Mexico Border allowing improved timing of the arrival of Border Patrol agents at suitable locations to safely conduct successful apprehensions. The logic of the Border Foot Trafficability Prediction Model is based on the concept the land cover and terrain features influence the rate of pedestrian travel and the length of time required to travel a given distance.

Eight dominant and four lesser variables were selected for inclusion in the prediction model based on the strength of their influence on pedestrian travel rates. The variables selected include pedestrian age, pedestrian gender, terrain slope, terrain aspect, vegetation type, vegetation density, vegetation height, presence of roads or trails, surface illumination, temperature, distance traveled and wet or dry trail conditions.

Predictions were made using four different pedestrian rates-of-travel for a study area within the San Diego Sector of the U.S. – Mexico border using ESRI's ArcGIS least cost path software application. Land cover effects such as vegetation and terrain and the presence of trails were

found to significantly alter pedestrian rates-of-travel. Areas of rapid travel corresponded to regions that were flat or had gentle slopes with little or no vegetation to hinder pedestrian movement. Area of reduced travel rates corresponded to regions with steeper slopes and/or dense vegetation. Trails and roads increase the rate of movement, especially in densely vegetated areas. In the rugged terrain of the study area, smugglers could be anticipated to cross the 1 km wide study area in between 20 and 30 minutes.

Conclusions
Pedestrian travel time horizon maps reveal informative patterns and spatial relationships that can be used to improve border containment operations. Visual inspection of Figure 68 shows a correlation between routes of rapid travel (low travel time horizon values) and border apprehensions suggesting routes with the shortest travel times are preferred by border crossers over other routes. There also appears to be a strong correlation between the intersection of roads (Border Patrol routes of travel) and border crosser routes of rapid travel with border apprehensions suggesting that roads play a key role in transporting agents to suitable apprehension locations. Reviewing travel time maps offer the potential for improved containment zone apprehension and tactical planning. Such maps have the potential to identify routes most preferred by border crossers. The maps can also suggest which routes provide the shortest travel time within the containment zone. Examining the relationship between trails and existing Border Patrol roads could be used to identify optimal interdiction locations along high rate-of-travel routes. Future roads could also be designed to provide quicker interdiction response times by carefully designing their locations. Rate-or-travel maps could also be used to locate observation locations providing the greatest visible coverage of high-use trails. Sensor locations could also be tailored to locations along preferred trails to allow earliest detection and maximum interdiction time. Locating preferred routes may suggest potential rendezvous points and "lay-up" locations along such routes. Knowing the routes and patterns of border crosser travel may also allow for improving interdiction tactics, planning, personnel allocations and training allowing new agents to become highly proficient sooner. Figure 68. Graphic displaying pedestrian travel time horizons in color overlain with roads, trails and 2004 and 2005 apprehension locations. Many apprehension locations appear to be located near or along routes of rapid movement.

2.3.3 Outcome Document: Clandestine Airfield Location Prediction Model

Citation
Kaiser, J. and Stow, D. 2006. Model Guide: Clandestine Airfield Location Predication Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document
Kaiser_2006_Clandestine_Airfield.pdf

Abstract
Protecting America's international borders has become a high priority for the agencies of U.S. Customs and Border Protection. Since the terrorist attacks of 11 September, 2001, emphasis has shifted to preventing the smuggling of people and materials into the United States for terrorist purposes. Large portions of America's southern border are remote and sparsely populated and as a result are extensively used to smuggle people and contraband. Smugglers and terrorists are highly adaptable, reacting to new border security measures by shifting routes and changing modes of transportation. Even with the evolutionary adaptation of advanced technology to perform border surveillance, air trafficking of people and contraband continues as a threat to U.S. security. Air smuggling into northern Mexico's border regions adjoining the U.S. and into the U.S. continues to evolve.

Among the most significant systems for detection and interdiction of smuggler aircraft along the southern border with Mexico is the Tethered Aerostat Radar System or TARS. The strengths and weaknesses of the TARS system influence to a large degree the routes and clandestine airfield destinations of air traffickers. Southern California and Arizona are dotted with tiny airstrips and hundreds of abandoned or clandestine ones. Drug traffickers often use these airstrips to smuggle illicit drugs into the United States. Occasionally, pilots evade radar and land at remote locations in Southern California including abandoned airstrips or long stretches of highway. Furthermore, smugglers are known to establish clandestine airstrips near the U.S.-Mexico border to further facilitate their smuggling efforts.

Clearly, not all smuggling flights are deterred by TARS along the U.S. southern border. Although the TARS is among the first lines of defense against smugglers and terrorists using aircraft to cross our national borders, determining their destination once across the border is critical to apprehension by law enforcement agencies. Radar fade data and airborne surveillance operations suggest that some border regions are more prone to air trafficking than others. Knowing the location of active and inactive airfields, as well as remote sites suitable for use as temporary airfields allows law enforcement agencies to improve apprehension activities. The Clandestine Airfield Location Prediction Model uses remotely sensed imagery and geospatial technologies to assist in identifying these destination airfield locations. Although the prediction model concentrates on predicting the location of potential destination landing sites for air traffickers, it does so in the context of the border radar surveillance system that most influences the routes and ultimate destinations of air trafficker flights.

Six variables were selected for the prediction model based on the behavior patterns of air traffickers. The variables selected included ground slope, potential for observation by the public and general aviation communities, proximity to transportation networks, presence of ground-surface obstructions (principally vegetation), visibility by law enforcement radar (TARS), and suitable airfield length (size). Data availability was a principal consideration in parameter selection.

The model identified approximately 139 square miles (360 sq km) that met the general physical criteria necessary for an airfield surface from within the 4255 square miles (11,020 sq km) of the San Diego County study area. Using minimum size criteria for short 1200 ft (365 m) and longer

2500 ft (762 m) runways, 161 locations suitable for short landing strips and 33 suitable locations for long landing strips were identified. The combined areas for short and long landing strip areas were 29 square miles (75 sq km) and 16 square miles (41 sq km), respectively. Model results suggest that dramatic reductions in the potential destination areas requiring monitoring can be achieved through use of the modeling strategy developed in the Clandestine Airfield Location Prediction Model.

Conclusions
Spatial suitability modeling was conducted and greatly reduced the spatial extent of the San Diego County study area requiring evaluation for further locations of clandestine airfields. In its current configuration, the Clandestine Airfield Location Prediction Model suggests spatial reductions of potential landing sites in excess of 95 percent (139 Sq Miles / 4255 Sq Miles) for the San Diego County study area. As runway length criteria is increased, the number and area capably of supporting longer airfields is rapidly reduced within the San Diego study area as observed by the reduction from 161 to 33 sites when assessing for short to long runway lengths. The identification of specific locations for airfield assessment allows the targeted use of other law enforcement resources to determine the presence of a landing strip and the likelihood of its exploration as a smuggler airfield. The identification of high-probability target areas allows law enforcement agencies to focus search and monitoring activities on likely landing sites greatly reducing unproductive surveillance and interdiction efforts. Additional benefits include an improved ability to interpret law enforcement human intelligence data (humit), and radar fade data while reducing costs and increased the probability of successful apprehensions.

2.3.4 Outcome Document: Stability, Normalization and Accuracy of MODIS-derived Estimates of Live Fuel Moisture for Southern California Chaparral

Citation

Stow, D. and Niphadkar, M. 2007. Stability, normalization and accuracy of MODIS-derived estimates of live fuel moisture for southern California chaparral. *International Journal of Remote Sensing Letters*, 28(22): 5175-5182.

PDF Document
Stow_2007_MODIS_live_fuel_moisture.pdf

Abstract
Time series of spectral vegetation indices (SVIs) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) and live fuel moisture (LFM) data for chaparral vegetation of southern California were extended to include one of the driest (2004) and one of the wettest (2005) years on record. Independent, spatially varying field-based estimates of LFM enabled accuracy of MODIS-derived estimates to be quantified. Pixel-based scaling of SVI values based on maximum and minimum values of the time series reduced effects of varying vegetation cover and substantially reduced root mean square errors for two of the three SVIs tested.

Results and Conclusions

Scatter plots and regression model results for LFM versus each of the three standard SVIs and each of the max–min scaled SVIs are shown in figure 1. Coefficient of determination (r^2) values were higher for the max–min scaled versions of all three SVIs. The highest r^2 (0.75) resulted from the regressions of LFM on max–min scaled NDII6 and scaled VARI, while the lowest r^2 was 0.53 for the LFM vs. standard NDII6 regression.

Compared with the regression results from Stow et al. (2005) that were based on a 3-year time series, regression slopes and intercepts for the 2000–2005 time series of standard SVIs were nearly identical, and r^2 values were similar (except NDWI, which increased substantially). The inclusion of the Rainbow site data for the 2004 drought year and the very wet year of 2005 added little scatter to the linear regressions, but results suggest that the models based on 3 years and 5 years of data are stable.

The spatially based validation of MODIS-derived LFM estimates reveals that max–min scaling substantially reduced root mean square errors (RMSEs) by 49%, 62%, and 2% relative to the non-scaled NDII6, NDWI, and VARI, respectively. The greatest reduction in error and lowest RMSE resulted for scaled NDWI, with an RMSE of 23.9% for the standard and 9.1% for the max–min scaled version. The RMSE of scaled VARI (13.9%) was only slightly less than the non-scaled VARI (14.6%).

When mapping LFM as 10% interval classes, as was done by Stow et al. (2006), the scaled version of NDWI should yield the highest accuracy. Interval classes from max–min scaled NDWI were in agreement with fieldbased classes for six of 11 sites, and for three of the other sites the classes were off by one interval class. The magnitude of mean absolute difference and RMSE values for the LFM estimates based on scaled SVI values suggest that 10% intervals are appropriate for map representation (i.e. as a balance between precision and error/ uncertainty).

In summary, these results suggest that regression models of MODIS-derived SVIs versus field-based LFM estimates based on 3 years and 5 years of data are stable, and models for max–min scaled SVIs explain a high degree (approximately 75%) of the temporal co-variability with LFM. Pixel-based scaling of SVI values by the record length maximum and minimum values was found to reduce LFM estimation errors based on independent LFM estimates sampled across San Diego County. Given such reductions in errors and increases regression coefficients, and that reductions in error estimates were lowest for scaled VARI, an SVI that is primarily used to estimate vegetation fractional cover, the max–min scaling seems to be effective in reducing spatially varying effects of vegetation cover on SVIs based on NIR and SWIR wavebands.

2.3.5 Outcome Document: Integrating Fire Behavior and Trafficability Models to Assess Fire Danger to Pedestrians Within The San Diego- Mexico Border Zone

Citation

Anguelova, Z. 2007. Integrating Fire Behavior and Trafficability Models to Assess Fire Danger to Pedestrians Within the San Diego-Mexico Border Zone. Master's thesis. San Diego State University.

PDF Document

Anguelova_2007_Thesis.pdf

Abstract

The objective of this study is to develop tools and procedures for better assessing the danger of wildfire to pedestrians in rural areas. Furthermore, the main goal is to better understand the combined behavior of fire and pedestrian mobility in order to predict evacuation timing in wildland areas. The study involves the integration of the Wildland Urban Interface Evacuation (WUIVAC) model and a pedestrian trafficability model to determine zones of high fire danger during extreme fire season weather conditions within the US-Mexico border region of San Diego County.

A three step analysis approach will be used to test two scenarios. The first scenario involves a person (e.g. illegal crosser) moving in a northward direction on a trail toward a major road. For the second scenario, a person (e.g. law enforcement officer) will be located in dense vegetation, away from roads and safety zones walking toward an evacuation vehicle. The first step identifies areas located furthest away from roads and safety zones. In the second step, estimates of travel time are calculated considering terrain and vegetation constraints to movement. In step three, evacuation trigger buffers are generated by WUIVAC based on the pedestrian travel paths.

The study results show that the evacuation travel times calculated by the trafficability model are highly effected by the terrain and vegetation characteristics of the study site, while the ETBs extent are mostly influenced by the wind speed and direction parameters. The integrated models estimate a moderate fire danger to pedestrians in the most remote wildland locations of the study area.

General Conclusions

The GIS overlay and PTL models determined that for the entire San Diego-Mexico border zone the longest time for an average person to traverse the longest south-north trail is 105 min. considering terrain characteristics and vegetation types as impediments to travel. Based on the 105 min. ETB generated with WUIVAC for south-southwesterly and northeasterly winds, the closest locations where a wildland fire could occur relative to the entire trail that leave sufficient amount of time for a pedestrian to safely evacuate are 2 km. and 6 km. away, respectively. Considering this, a conclusion may be drawn that if a wildland fire occurs within 2 km. (for an extreme south-southwesterly winds) or 6 km. (for a northeasterly wind) from any location within the San Diego-Mexico border region a pedestrian would likely not have a sufficient amount of time to reach a nearby safety zone.

Two additional conclusions were drawn from this research regarding the shape of the THs and the shape and size of ETBs. First, upon examination of the irregular contours of the THs developed by the PTLM it was determined that faster travel rates are associated realistically with trails having lower slope angles and less vegetation cover compared to areas with no trails, higher slopes, and dense vegetation. This result was anticipated given that the rates of travel used in the PTLM were adjusted by the terrain characteristics and land-cover types of the study site. Second, the size and orientation of the ETBs generated by WUIVAC show positive relationships with the wind speed and direction used in FlamMap. Strong northeasterly (Santa Ana) winds were associated with the largest ETBs elongated toward the northeast, while the south-southwesterly winds produced smaller ETBs oriented toward the south-southwest.

Considering that the WFDMs are generated by the integration of the GIS overlay, PTLM and WUIVAC models and that the models were developed to be spatially explicit (they are not bound to one location), they can be used as a tool for development of fire danger maps for a variety of rural locations. For example, the GIS overlay model could be utilized to determine areas of high fire danger and safety zone locations for recreators and rangers at parks and wilderness areas. The PTLM could be utilized to calculate the time it takes an average hiker to traverse the trails at the park and ETBs could be generated for the trails for different weather conditions.

Considering that the WFDMs can be pre-generated for a specific area and weather conditions, they can be utilized by law enforcement officers and fire managers as a reference during safety briefings, during a wildland fire, and to educate the population of a rural area, not only about the potential fire danger, but also to show them possible safety zones in the vicinity of their dwellings. Furthermore, WFDM can provide rescue teams and law enforcement officers general knowledge of high fire danger zones for which immediate help would be needed in order to assist pedestrians who might be at danger to a wildland fire.

In the future, WFDMs could be developed for real time wildland fire event by incorporating current wind and fuel moisture data to the FlamMap model in order to generate ETBs that are representative of the current conditions. In addition, the pedestrian base travel rate used for the calculation of travel time horizons in the PTL model could be adjusted to account for the physiological characteristics of the people at danger to the wildland fire. However, such real-time, operational usage of the integrated models extends beyond the intended and more appropriate utility, which is as a fire danger assessment and planning tool.

2.3.6 Outcome Document: Integrating Real-time National Weather Service Information for the San Diego Border Region

Citations

Kaiser, J., T. Zhang, and M. Tsou. 2008. Integrating Real-time National Weather Service Information for the San Diego Border Region. Department of Geography, San Diego

State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kim, I., J. Kaiser, T. Zhang, and M. Tsou. 2008. Integrating Real-time National Weather Service Information for the San Diego Border Region - **Supplemental Report**. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Documents
Kaiser_et_al_2008_Border_Climatic_Report_Final.pdf
Kim_etal_2008_Border_Climate_Report_Supplement.pdf

Abstract
San Diego border region is an important sector along the U.S.-Mexico border. The harsh climate in this and other sectors along the arid southwest border poses dangers for undocumented immigrants, as well as for Border Patrol (BP). Delivering real-time weather information on the Web can enable the BP agents to be better prepared to save lives. The National Digital Forecast Database (NDFD) hosted by the National Weather Service (NWS) can be used to achieve this goal. This report details a mechanism to provide real-time weather forecast information in a simple and automatic way. The three major software components of this mechanism are NWS Degrib program, ESRI ArcIMS, and Softtree 24x7 Scheduler. The three integrated software can refresh the Web-based weather information services at specified time intervals. This simple method can be extended to incorporate other weather data as well other Internet-based GIServices to better support border security decision-making.

Conclusions
This report introduces procedures for using Internet GIS technologies to deliver real-time weather forecast data. As discussed, this technology can be potentially useful for Border Patrol operations. The weather mapping services can then be integrated with more geospatial information such as wildfire, earthquake information to enhance emergency responding efficiency. In conclusion, GIS technologies can be geared toward the special needs of homeland security and produce enormous benefits in both the short and long run.

2.3.7 Outcome Document: Tunnel Location Prediction Modeling

Citation
Kaiser, J. and Stow, D. 2004. Tunnel Location Predication Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document
Kaiser_2004_Tunnel_Report.pdf

Abstract
Twenty-three tunnels have been found along the U.S.-Mexico border between 1990 and August 2004. Eleven were in the San Diego County region. Law enforcement agencies on both sides of the border believe drug trafficking organizations (DTO's) are relying more on tunnels to avoid tightened security at U.S. ports of entry following the terrorist attacks of September 11, 2001.

Using geographic information system methods, a site suitable model to identify areas likely to be exploited for tunnel construction was developed exploiting characteristics of geology, soils, water table, transportation networks, border proximity and other parameters to identify suitability sites. High probability areas matched well with earlier geology based predictions, law enforcement intelligence data and previously discovered tunnel locations. The model identified several areas not previously considered exploitable for tunnel excavation.

Results from Tunnel Location Prediction Model identified 18 locations (5 % by length) astride the 106 km (66 mile) long San Diego County portion of the U.S. – Mexico border likely to be exploited for the construction of clandestine transborder tunnels. Six border segments totaling 2.3 km (1.4) miles were located along the 23.3 km (14.5 mile) long Tijuana-San Diego metropolitan border with an additional 12 segments totaling 3.5 km (2.2 miles) in length located along the 72 km (45 miles) of rural backcountry border.

Conclusions
Results from Tunnel Location Prediction Model reduced the length of U.S. – Mexico border within San Diego County considered likely for border tunneling from 106 km (66 miles) to 5.8 km (3.6 miles) in length. The model identified 18 locations likely to be exploited for the construction of clandestine transborder tunnels. Six border segments totaling 2.3 km (1.4 miles) were located along the 23.3 km (14.5 miles) long Tijuana-San Diego metropolitan border with an additional 12 segments 3.5 km (2.2 miles) located along the 22 km (51 miles) of rural backcountry border. Identification of these locations allows for a significant reduction in the expenditure of ground-based tunnel detection resources and a greater focusing and tailoring of detection activities to the unique geologic and topographic characteristics of likely sites.

The benefits derived from this study include obtaining and integrating information suggesting the location of existing and suspected tunnel locations astride the San Diego Sector of the U.S. – Mexico border. This information, along with vector maps showing the locations of known tunnels and areas along the border exploitable for future tunnel construction, can be directly integrated into the U.S. Border Patrol's SSDS. The US Border Patrol can use this information to enhance active, passive and tactical tunnel detection activities. Benefits include reducing and focusing operational monitoring resources to those areas of highest likelihood for tunnel exploitation. Such operational activities include field agent deployment, specialized training and allocation of high technology sensors to high-probability areas. One of the greatest enhancements is the ability to improve interpretation of law enforcement intelligence data, sensor alerts, and identification of surrogate tunnel indicators – potential portal locations, tunnel excavation spoils, unexplained sensor annunciations, unexplained increases in drug traffic, etc.

2.3.8 Outcome Document: Integrating fire behavior and pedestrian mobility models to assess potential risk to humans from wildfires within the US-Mexico border zone

Citation
Anguelova, Z., Stow, D., Kaiser, J., Dennison, P. and Cova, T. Accepted May 2009. Integrating fire behavior and pedestrian mobility models to assess potential risk to humans from wildfires within the US-Mexico border zone. *Professional Geographer*.

PDF Document
Anguelova_2009_Prof_Geog_Manuscript.pdf

Abstract
Wildfires create a risk to pedestrians traveling through rural areas, since they might not be aware of the presence of a wildfire or its direction and rate of spread until is too late to successfully evacuate. In wildland areas of southern San Diego County, immigrants crossing the US-Mexico border and border security agents are particularly at risk to wildfires. The objective of this study is to develop a framework of analysis and associated tools for examining the combined behavior of wildfires and pedestrian mobility in order to assess the potential threat of fire to pedestrians in wildland areas. Outputs from a GIS overlay model for determining potentially dangerous fire zones, the Wildland Urban Interface Evacuation (WUIVAC) model, and a model of pedestrian mobility in wildland areas, were combined to generate wildfire risk to pedestrians maps. The key technical contributions of the study are the development and testing of the Pedestrian Mobility Model, and the framework and logic for integrating the results of three GIS-based models. The applied geography contribution is the testing of two scenarios of high risk from wildfires to pedestrians within the US-Mexico border zone of San Diego County, California.

The study results show that the travel times calculated by the Pedestrian Mobility Model appear to be realistic and are affected by the terrain and vegetation characteristics of a study site, while the evacuation trigger buffers from WUIVAC are mostly influenced by the wind speed and direction parameters of the FlamMap fire spread model. A moderate fire danger to pedestrians in the most remote wildland locations of the study area is determined. The scenario test results suggest that if a wildfire occurs within 2 km (extreme southwesterly winds) or 6 km (extreme northeasterly wind) of a pedestrian in the worst case location within the San Diego border region they would likely not have a sufficient amount of time to reach a nearby safety zone

Discussion and Conclusions
By combining the GIS overlay and PMM model results we determined that for the US-Mexico border zone within San Diego County, the pedestrian travel time for an average person to traverse the longest south-north trail is 105 minute (scenario 1). Based on the 105-minute evacuation trigger buffer generated with WUIVAC for severe case south-southwesterly and northeasterly winds, the closest locations where a wildland fire could occur relative to the entire trail, such that an northward moving immigrant with no knowledge of the fire or potential safety zones could safely evacuate would be 2 km and 6 km away, respectively. Thus, if a wildland fire is further than 2 km (for an extreme south-southwesterly winds) or 6 km (for a northeasterly

wind) a pedestrian at any location within the San Diego border region would likely have sufficient amount of time to reach a nearby safety zone.

Since wildfire risk to pedestrians maps are generated by the combining the output from the GIS overlay, PMM and WUIVAC models, and because the models were developed to be spatially explicit (they are not bound to one location), they can be used as a tool for development of fire danger maps for a variety of rural locations and scenarios. For example, the GIS overlay model could be utilized to determine areas of high fire danger and safety zone locations for hikers, campers, and rangers within parks and wilderness areas. The PMM could be utilized to calculate the time it takes an average hiker to traverse the trails at the park and evacuation trigger buffers could be generated for the trails for different weather conditions. However, the most original and novel contribution of the study is the development of the framework and logic for integrating the outputs of these three distinctly different GIS-based models. No previous published studies have examined the potential of geospatial models for quantifying the site-specific wildfire hazard associated with pedestrians traveling across wildland areas.

If wildfire risk to pedestrians maps were pre-generated for a specific area and weather conditions, they could be utilized by law enforcement officers and fire managers as a reference during safety briefings, for wildland fire evacuation planning, and to educate the population of a rural area. Furthermore, wildfire risk to pedestrians maps can provide rescue teams and law enforcement officers general knowledge of high danger zones for which immediate help would be needed in order to assist pedestrians who might be at risk to a wildland fire.

In the future, wildfire risk to pedestrians maps could be developed for real time response to wildland fire events by incorporating current wind and fuel moisture data to the FlamMap model (or other fire spread models) in order to generate evacuation trigger buffers that are representative of the current conditions. In addition, the pedestrian base travel rate used for the calculation of travel time horizons in the pedestrian mobility model could be adjusted to account for the physiological characteristics of the pedestrians at risk to the wildland fire. However, such real-time, operational usage of the combined models extends beyond the intended and more appropriate utility, which is as a fire danger assessment and planning tool.

Improvements to the wildland risk to pedestrians maps may be accomplished by enhancing the GIS overlay, PMM, and WUIVAC models and conducting a thorough analysis of potential errors and uncertainties in the individual and combined model outputs. Site-specific rules for determining safety zones could be developed. In this study, major roads and recent fire scars were considered as safety zones, but in other areas agricultural fields, water bodies, or large rock outcrops could be considered as safety zones. The PMM could be adjusted to predict walking times for children, elderly people, men, women, and/or pedestrians with high fitness levels. Developing and testing relationships between image-derived NDVI and off-trail impedance to pedestrian travel is warranted if PMM is to be used for estimating travel times in areas void of trails, or situations where off-trail travel is more likely. Improvements and enhancements to the inputs and approaches to fire spread modeling would likely yield more realistic estimates of evacuation trigger buffers. For example, incorporation of spatially and temporally varying wind

fields should improve the ability to estimate fire spread rates and therefore, the derivation of evacuation trigger buffers.

2.4 Wireless Mobile GIS and Integrated Web GIS

The major objective of this task area is to establish and test an integrated framework combining web GIS and wireless mobile GIS technologies for border security decision support systems. The ultimate goal is implementation of this technology by within the Border Patrol, so that agents in the field utilize mobile GIS devices (Pocket PC) to access critical maps, imagery and geospatial information via secured wireless channels. Development and integration of a near real time spatial decision support system prototype which combines real time GPS tracking, GIS Web portals, online mapping services, and real time in-field agent data update will help optimize tactical and strategic border management and law enforcement tasks.

2.4.1 Key Accomplishments

An integrated spatial decision support system (SDSS) relies on three major components: Internet GIS, mobile GIS, and broadband wireless communication networks. Each component needs to be customized and integrated to provide real time or near real time GIS functionality. Interoperability and upgradeability are the two key issues for successful system integration and long-term operation with an SDSS because these GIS technologies change very rapidly. This project addressed several challenges in creating an interoperable SDSS framework. The key accomplishments for this research component are listed below by topic area.

Wireless Mobile GIS:

- Test the mobile GIS technology with Mission Trail Park Ranger (2004)
- Real-time tracking function development with ArcPAD (2005) (Jesse Hong and Batian Schaeffer)
- Testing and adoption of mobile GIS by SDSU campus Police for security enhancement (Jesse Hong's thesis work)
- Introduce new Mobile GIS platforms in Google Android and Apple iPhone SDK.
- Key outcomes and publications: two journal articles (Tsou, 2004; 2005), two master thesis (Hong and Yang), and two white papers for mobile GIS technology (2005 and 2008)

Integrated Web GIS:

- Prototype testing on ArcIMS (2004), ArcWeb Services demo (2006), ArcGIS Server (2008, 2009).
- San Diego 2007 Wildfire Mapping Services (http://map.sdsu.edu) with one technical report on the integration of NASA remote sensed imagery products and other satellite imagery for San Diego 2007 wildfire response.
- Automatic Weather Services for San Diego Border Regions (ArcIMS 9.3 + Scheduler). This web service is regularly used by San Diego Sector Border Patrol agents.
- Spatial Analysis function on ArcGIS Server 9.3 (with Google API) on the Demo page.

- Key outcomes and publications: two journal articles (Zhang and Tsou, 2005, Geographic Information Science and IJGIS (in press)), One Ph.D. dissertation (Tong Zhang),. and two white papers on "Integrating Real-time National Weather Service Information for the San Diego Border Region".

2.4.2 Outcome Document: Dynamic Multi-user Tracking in Wireless Environments with Mobile Geographic Information Systems (GIS) and Web-based Campus Mapping Applications for Monitoring Campus Crime: A Case Study at San Diego State University

Citation
Hong, J.E. 2007. Dynamic Multi-user Tracking in Wireless Environments with Mobile Geographic Information Systems (GIS) and Web-based Campus Mapping Applications for Monitoring Campus Crime: A Case Study at San Diego State University. Master's thesis. San Diego State University.

PDF Document
Hong_2007_FinalThesislDraft2.pdf

Abstract
This research created and evaluated a prototype of a real-time mobile Geographic Information System (mobile GIS) for reporting campus crime activities at San Diego State University. The integration of mobile GIS technologies (GPS, mobile GIS receivers, mobile GIS software, and wireless communication) and a Web-Based mapping application is the main focus of this research. To evaluate the usability of the mobile GIS prototype, a practical user scenario and a questionnaire were created. Public safety officers at San Diego State University (SDSU) were invited to participate in this research. For the comparison purpose, SDSU students also evaluated this prototype.

The development of prototype was accomplished by customizing ESRI's ArcPad and ArcIMS with programming languages, Visual Basic Script (VBS) and Hypertext Markup Language (HTML). ArcPad was installed on a Pocket PC, and performed integrated mobile GIS function with a wireless Bluetooth GPS receiver. ArcIMS was used to store GIS map layers in the server and to publish a Web-Based campus map. A client (Pocket PC) and a server were synchronized by using File Transfer Protocol (FTP) in real-time. A total of 30 users were invited to test this prototype in the SDSU campus, consisting of eight undergraduate, 12 graduate students, and 10 public safety officers. User testing consisted of field testing and questionnaire survey. In order to analyze feedback from the tester, quantitative (ANOVA) and qualitative (SWOT) analyses were adopted in this study.

Statistically, all participants rated the usability of the mobile GIS prototype as easy to use. Different level of GIS background was not affecting the evaluation scores. From comparing the Web-Based campus map and the paper campus map, the Web-based map was superior in capability of providing accurate/detailed information and overall user preferences while more

users chose the paper campus map in easiness to find. From the SWOT analysis method, most users suggested that the prototype was easy to use, and it had user-friendly interface. However, users identified that unstable wireless communication channels and GPS signal availability were major problems in the prototype.

This study provided a proof-of-concept for applying a real-time mobile GIS and a Web-based mapping application in campus safety management. The results from this research will provide valuable suggestions for the future development of mobile GIS applications in various fields, such as incident investigations, emergency responses, and environmental managements.

Conclusions

This research demonstrated the potential of integrating a real-time mobile GIS and a Web-based mapping application for campus safety management. The development of the mobile GIS prototype is a proof-of-concept for GIS related campus safety tasks. Collecting new crime data records in the field with GPS can help public safety officers to acquire and store crime data records with accurate location information. Also, the uploading crime incident report to the server function allows officers to share collected information between field police officers and dispatchers in the office in real-time. In addition, the Web-based campus mapping application provides detailed campus information and a high resolution aerial image with the capability to change scale and map contents dynamically.

Thirty participants tested and evaluated the prototype including 10 public safety officers from the Department of Public Safety, eight undergraduate and 12 graduate students in SDSU. From the statistical analysis, each testing group had different levels of GIS background. Graduate students group had the highest level of GIS background while public safety officers had the lowest. Other technologies' background such as Bluetooth, Wi-Fi, and Pocket PCs were similar in each user group. All participants (from GIS beginners to experts) could complete the testing of the mobile GIS prototype in similar duration of time. Even though there was a large difference in GIS background among different user groups, all testers evaluated the usability of the prototype very positively and suggested that the prototype was easy to use. It implies that non-GIS users can employ the mobile GIS prototype without having difficulties.

From the comparing the Web-based campus map to the paper campus map, reviewers were asked to find a specific campus building on both mapping applications, and then evaluated the context of easiness to find, accurate/detailed information, and overall preference. In easiness to find, 50% of users chose the paper campus map while 37% of users chose the Web-based one. In accurate/detailed information, 83% of participants chose the Web-based campus map, but only 10% of participants chose the paper map. In overall preference, 57% of tester preferred the Web-based campus map while 13% of tester preferred the paper map. Comparing between two groups – students and public safety officers can tell us each user group's preference between two mapping applications. Two categories, accurate/detailed information and overall preference, were similar in each group. However, in the category of the easiness to find, two groups' responds were opposite. 70% of officers chose the paper map, but only 10% of students chose the paper map. This result might be come from lack of public safety officers' GIS background. Therefore, in the future, training non-GIS users are important to raise usability level.

From the SWOT method, most reviewers identified that the mobile GIS prototype was easy to use, and interface was user friendly. They also responded that no additional learning curve was required to complete the testing. However, many of participants mentioned that unstable platform in wireless network connections and GPS signal availability was the major weakness of the prototype. In the case of opportunities, there would be enormous potentials to be applicable to other real-time applications such as law enforcement and fire department. Reviewers also identified possible additional functions to be included in the prototype for campus safety. For threats of the prototype, many reviewers addressed that more detailed tutorial would be helpful to test the prototype and give their opinions on the questionnaire. Also, they identified that assistance would be required for user testing.

Through the development, customization, evaluations, and analysis, four research questions, which were mentioned in the first chapter, were answered. The followings are the research questions and their answers based on the results of this research.

1 What kinds of system architectures are appropriate for developing wireless mobile GIS applications for campus safety management?
With the successful implementation of a mobile GIS in ArcPad and ArcIMS, the client-server framework was tested and demonstrated. Because ArcPad has build-in network Application Program Interface (API) and FTP functions, a mobile GIS client could send local data to the server with wireless communication easily. A Web server can update the GIS data in near real-time. At the beginning stage of the prototype development, automatic updating of the Web-based mapping application by uploading new crime data to the server was suggested. However, the automatic updating of the Web-based mapping application with new crime report data was not accomplished in this research due to the technical difficulties. Therefore, in order to update the Web-based mapping application, a user needs to republish the map manually with newly uploaded crime data via the FTP channel.

2 How effectively can a customized and integrated mobile GIS application assist GIS users for campus safety and crime reporting tasks?
Most reviewers evaluated usability of the integrated mobile GIS prototype very positively. They suggested that the prototype was easy to use and functional to use. From the usability test, many users rated usability of the prototype as somewhat between easy and moderate, but close to easy. Therefore, they expected a low learning curve to master the mobile GIS prototype. Testers also mentioned that this new prototype would be helpful for many campus safety and crime reporting tasks thank to capabilities of reporting new crime incidents with accurate location information and uploading collected data to the server in real-time.

3 What are advantages and disadvantages to utilize the Web-based campus mapping tools for campus safety comparing to traditional paper campus map?
Participants identified advantages and disadvantages of the Web-based campus mapping application. As advantages of the Web-based mapping application, participants mentioned that it provided more accurate and detailed information, realistic views with 3D images, and interactivity with users. Also, some of them mentioned that a map scale

could be changed with zoom in and out tools. However, participants identified disadvantages of the Web-based mapping application such as stiffer learning curve and requirement of connection with a computer.

4 What are the differences in evaluation for the mobile GIS application among three user groups (public safety officers, graduate students, and undergraduate students)?
The student group including graduate and undergraduate students had relatively higher background levels of GIS related technology than public safety officers while other technologies such as wireless and Bluetooth were similar. Difference of GIS background in each user group was the largest from ANOVA method. However, all user groups evaluated the overall usability of the prototype as easy to use, and there was no difference among user groups' responses on the usability evaluation. Therefore, it can be assumed that difference of the level of GIS background did not affect the evaluating usability of the prototype.

There were many challenges and limitations while conducting this study. As mentioned earlier, unstable mobile GIS platform was one of major limitations to deploy the prototype. Even though a Pocket PC showed that there was available wireless network in its range, connecting to it was difficult. Sometimes it took very long time to connect to it. In worse case, it did not connect at all. In order to solve this problem, an additional function is suggested in the future study. This new function will be used to store the calling method of "uploading data to the server" in the system when wireless network is not available. When wireless network is ready, data will be automatically uploaded to the server.
Also, unstable GPS signal activity was one of limitations. GPS could be affected by different weather condition. Testing the prototype was difficult when the weather was not good. Usually, receive rate of GPS signal is sensitive to the weather condition. In order to maintain a certain level of receive rate, new technology such as weather resistant GPS is under development. For the future mobile GIS research, it will be important to maintain stable platform.

Another limitation of this prototype was the size and user interface of the Pocket PC. Because the Pocket PC has small screen size, it was required to zoom in few times to view a specific building. Also, typing in crime information in a crime form was not user friendly because users had to click each word separately with a pen input device. For emergency responses, small screen size and unfriendly user interface of the Pocket PC could be a problem. Field workers need to choose the most suitable type to improve their work among various types of mobile GIS receivers. If field workers need to large screen size, they have to use tablet PCs instead of Pocket PCs. A type of Mobile GIS receivers has to be chosen depended on types of work and preference. Another solution for small keyboard of a Pocket PC is adopting a touch-screen keyboard interface which is currently used in Apple's iPhone. A user can fill out information with a finger rather than typing with a pen input device. Also, one of possible solutions is a voice recognition system which allows to convert spoken word to computer text. The touch-screen keyboard interface and the voice recognition system will help to save time to input data into a Pocket PC.

This research has shown the potentiality and usability of integration of a mobile GIS and Web-based mapping applications. Public safety officers can manage campus safety and report crime incidents in a more efficient way by collecting crime information with GPS and Pocket PC devices. Officers can upload the records to the server in real-time. The results of this study provide a good demonstration to illustrate the future direction of development of a real-time mobile GIS and Web-based mapping applications.

As the future application, LBS can be one of possible applications for campus safety management. With LBS, police officers can obtain related crime data and photos in real-time. Tracking a criminal will be another possible function in LBS. Also, students can make a crime incident report to police officers by their cellular phones in real-time. In addition, future wireless technology will help to improve a mobile GIS functionality. WiMAX which provides the high speed data and telecommunication services, will support to develop stable mobile GIS applications. Lastly, in order to develop a two-way communication between a mobile client and a map server, ESRI's ArcGIS Mobile is suggested. ArcGIS Mobile is available for an automatic two-way communication with ArcGIS Server in real-time. These new technologies will be helpful to develop more advanced and powerful mobile GIS applications in the future.

2.4.3 Outcome Document: New Technologies of Mobile GIS

Citation
Kim, I., Y. Tsai, and M. Tsou. 2008. New Technologies of Mobile GIS. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document
Kim_etal_2008_mobile-GIS-new-technology-final.pdf

Introduction
As mobile devices such as Tablet PCs and Personal Digital Assistants (PDAs) were emerged, GIS were able to also extend from office desktops to such mobile devices. The advent of mobile GIS allows fieldworkers to manage data directly in the field. Mobile GIS can be used when to create and edit data by an engineer, when to maintain assets by a manager, when to inspect and report incidents by the police, and when to drive on the roads. Although a variety of mobile GIS solutions are utilized around us, mobile GIS has evolved continuously as the mobile technologies have seamlessly developed. In particular, the recent advancements of wireless technologies broaden the potential of mobile GIS applications.

Mobile GIS can be used with or without wireless networks. Until now mobile GIS has been commonly used without using wireless networks. Field workers collect and store their data in handheld devices and process data in an office after field works. This disconnected mobile GIS needs only separate mobile devices and do not need to consider server client architecture. Thus, it is not expensive to implement the disconnected mobile GIS and mobile GIS users have only to

purchase mobile GIS tools. Functions of mobile GIS are also focused on obtaining more accurate data and the costs of mobile GIS have depended on the accuracy of GPS.

However, as computer environments have changed into wireless networks, it is expected that the applications of mobile GIS will drastically extend. By using mobile GIS, field workers will be able to collect and validate data on the site and they will be able to deliver and receive data from a server over wireless networks. Field workers will share their information with each other and personnel in an office can relay data obtained from field workers. This will reduce a lot of work procedures. In particular, if the WiMAX, which is a new wireless technology, can be matured in the U.S., mobile GIS can meet accumulative requests of mobile GIS users in terms of real time data managements.

In addition to the development of wireless technology, new digital technologies are incorporated into mobile devices. Digital cameras and range finders as well as GPS are applied into mobile GIS. These trends allow mobile GIS to broad its applicable areas. By using GPS and wireless network, a company can monitor and manage its vehicles. Integrating GPS and digital photos allow mobile GIS to better understand human behavior. The accumulation of location information gathered from mobile GIS make users to capture spatial phenomena faster, more effectively, and more exactly.

Since mobile GIS technologies are newly updated, now is the time to plan how to utilize these new technologies. In order to do that for potential applications, we need to know which new mobile technologies are. From that perspective, this paper will represent recent developments of software, hardware, and network technologies respectively, which are the key components of mobile GIS.

Conclusion

Although mobile GIS has weaknesses such as small display size, lower performance than a PC, the potential areas of mobile GIS applications increase as wireless network technologies is developed. Until now, mobile GIS is used for simply data gathering and event reporting but the trends of mobile GIS will be changed into real time communication. Then, mobile GIS can play a role to share spatial information and to construct knowledge in real time. In particular, integration of a variety of sensors such as rangefinders, RFIDs, and barometric pressure sensors as well as GPS will allow mobile GIS to collect and share information more powerfully.

These new mobile GIS technologies can be applied into the United State Border Patrol (USBP). The USBP can display photos on the map and better understand the tendency of immigrants. This location information can be utilized to analyze immigrant pattern and plan strategies to reduce them. In addition, the USBP can monitor the locations of its agents and adjust their movements.

The USBP may not need to use accurate and expensive GPS toolset. Instead, cheaper and multi-functional handheld devices such as JunoST seem to be appropriate for their works. If the wireless technology is more matured, potential application of mobile GIS for the USBP will increase because agents will be able to retrieve data and send their report in real time.

2.4.4 Outcome Document: Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management

Citation

Tsou, M.H. 2004. Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management. *Cartography and Geographic Information Science*, 31(3): 153-165.

PDF Document
Tsou-2004-CaGIS-Integrated-Mobile-GIS.pdf

Abstract
With the progress of mobile GIS technology there is a great potential for adopting wireless communications and Internet mapping services for regional environmental management programs and natural habitat conservation. This paper provides an overview of a NASA-funded research project that focuses on the development of mobile GIS tools and wireless Internet Map Server (IMS) services to facilitate environmental monitoring and management tasks. By developing and testing wireless Web-based map/image servers, mobile GIS applications, and global positional systems (GPS), this research created an integrated software/hardware infrastructure for a prototype mobile GIS application. The mobile GIS prototype allows multiple resource managers and park rangers to access large-size, remotely sensed images and GIS layers from a portable web server mounted in a vehicle. Users can conduct real-time spatial data updates and/or submit changes back to the web server over the wireless local area network (WLAN). This paper discusses in general the major components of mobile GIS, their current technological limitations, and potential problems during implementation. Key research agenda for mobile GIS are identified with suggestions for future research and development

Conclusion and Suggestions for a Research Agenda
The integration of mobile GIS technologies and wireless telecommunications was the key focus of this study, which utilized mobile GIS application software, global positional systems (GPS), and wireless networking technologies (IEEE 802.11b, Wi-Fi standard). The integrated mobile GIS framework provided natural-habitat conservation and land management program resource managers with integrated mobile geospatial information services that supported and helped optimize their field-based management tasks. The utilization of commercial off-the-shelf (COTS) mobile GIS software and hardware components help local government agencies to justify and obtain budgets to acquire mobile GIS systems. During user scenario testing, several challenges to the development of mobile GIS applications were identified. The following discussion summarizes these challenges and their possible future solutions.

The first challenge to implementing wireless mobile GIS is the short communications range of wireless networks and the requirement for broad bandwidth communications. Currently, most existing wireless LAN technologies are capable of only short-distance data transmissions ranging from 100 to 300 meters, which is not adequate for most field-based mobile GIS tasks.

On the other hand, cellular phone networks have extensive spatial coverage for their wireless signals but lack broad bandwidth. To solve this problem, one possible solution would be to utilize broad bandwidth communication systems such as the High Performance Wireless Research and Education Network (HPREN) (http://hpwren.ucsd.edu) to provide long-distance wireless networking capability in the Wi-Fi mode. Also, the recent development of the IEEE 802.16 standard may become a potential wireless network solution for mobile GIS. The IEEE 802.16 standard defines the Wireless Metropolitan Area Network (MAN) Air Interface for broadband wireless access in large urban areas (http: //grouper.ieee.org/groups/802/16/index.html) with a scalable solution to extend fiber optic backbones. On the software development side, the design of new data compression technologies for both vector data and raster imagery via wireless networks may also facilitate the transmission of large datasets for mobile GIS applications in the future.

The second challenge is in the map display and user interface design of mobile GIS applications. Since the screen display of most mobile GIS receivers is significantly smaller than those of desktop computers, viewing maps and manipulate GIS layers on their small screens is rather difficult. In addition, most mobile GIS receivers do not have screens with highcontrast display when viewed in direct sunlight. The GIS industry and community will need to re-think the design issues of mobile GIS software and provide Vol. 31, No. 3 163 more intuitive and user-friendly user interfaces for mobile GIS applications. One potential solution is to adopt multimedia technologies (sound, animation, and hyperlinks) to improve the inherent restrictions on mobile devices (Gartner 2003). Also, by adopting 3D visualization of landscapes/buildings (Rakkolainen and Vainio 2001) and using augmented reality in urban environments (Haala and Bohm 2003), mobile GIS users could navigate local areas more efficiently and effectively.

The third challenge is to integrate Internet mapping technologies into mobile GIS. Most on-line GIS applications were designed originally for desktop clients and standardized web browsers (Plewe 1997; Tsou 2004). Many technologies, such as Java 2D API (Sun Microsystems, Inc. 2003), Java applets, and Microsoft Active Server Pages (ASP) functions, cannot be accessed or executed in Pocket PC environments or require additional plug-in software. Moreover, the heterogeneous software environment of desktop- based Internet mapping solutions may become another problem for the integration of mobile GIS applications. One possible solution is to follow the OpenGIS Location Services (OpenLS) specifications developed by the Open GIS Consortium (OGC 2003a). OpenLS is an open software development platform for location-based application services, which utilizes XML-based Abstract Data Types (ADT) and the GeoMobility server (OGC 2003a; 2003b). The ADT was created by XLS, which is an XML-based language for location services. There are six major services defined by the OpenLS specifications: directory, gateway, location utility, presentation, route, and navigation services. Hopefully, the future development of OpenGL can be combined with other types of web services (Kolodziej 2002), such as Microsoft's .NET Framework or Sun's Java 2 Platform Enterprise Edition (J2EE) to provide more comprehensive technological frameworks for mobile GIS applications.

A fourth challenge is to provide intelligent mobile GIServices for different users with the help of software agents (Tsou and Buttenfield 2002). Different mobile GIS tasks will require distinct

design of user interface, Internet mapping technologies, and communication channels. From a mobile GIS user's perspective, it is very difficult to access hundreds of different Internet map servers and to find out about appropriate location services at the same time. One possible solution is to adopt software agent technology to help users access or request data/images from multiple servers with automated mapping and GIS overlay functions. Software agents interact with different mobile GIS devices to provide customized user interfaces, to assign appropriate color and symbols for different GIS layers, and to search available wireless channels. The adoption of software agents might also solve the problem of information overload for mobile GIS users and provide automated data conversion and better integration methods for mobile GIS applications.

A final challenge is the data protection issue in wireless mobile GIS applications. Some mobile GIS applications may utilize classified or proprietary GIS data gathered from the field or through access to classified databases. The classified information needs to be protected from unauthorized access in both mobile GIS devices and via wireless communication channels. Currently there are very few preliminary solutions for the protection of sensitive GIS data, such as password protection and data-encrypted transmission.

The real challenge for securing mobile GIS applications is to create a hierarchical security framework to define different user groups (administrators, special- access users, regular users, guests) with different permissions to access various security levels of geodata from a single GIS content server. Such a solution will require not only the progress of future mobile GIS technologies, but also participation from both administration-level users and field workers. Moreover, some field-based data, such as census tracks and parcel records, may involve potential problems of locational privacy (Monmonier 2003). For example, a homeowner may not want to share his/her annual income information with a public utility worker who needs to repair the power line near his/her house. The GIS community needs to develop strategic guidelines for the issues of data protection and locational privacy.

In summary, this research demonstrated that an integrated mobile GIS framework can provide field personnel and first responders with mobile geospatial information services that directly support and help optimize their field-based collection, analysis, and resource management tasks. Mobile GIS is a very promising technology with strong demands from both field-based workers and GIS vendors. With the progress of new mobile GIS technologies, many future applications (such as homeland security, emergency rescue, real-time environmental monitoring, virtual tour guides, wildfire management, and vehicle navigation services) will benefit from, and ultimately rely on, mobile GIS technology.

2.4.5 Outcome Document: Mobile GIS Technology Summary

Citation
Tsou. 2005. Mobile GIS Technology Summary. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document
Tsou_2005_Mobile_GIS_Technology_Summary.pdf

Abstract
The purpose of this research component is to establish an integrated framework by combining Web GIS and wireless Mobile GIS for border security decision support systems. These research activities are supervised by Dr. Ming Tsou.

An integrated spatial decision support system (SDSS) relies on three major components: Internet GIS, mobile GIS, and broadband wireless communication networks. Each component needs to be customized and integrated to provide real time or near real time GIS functionality. Interoperability and upgradeability are the two key issues for successful system integration and long-term operation with an SDSS because these GIS technologies change very rapidly. This project addresses several challenges in creating an interoperable SDSS framework.

Conclusions
In summary, the project team continues to address integration issues associated with the development of real time or near real time spatial decision support system prototype. By combining real time GPS tracking, GIS Web portals, online mapping services, and real time in-field agent data update, the establishment of a Web-based decision support system will help optimize tactical and strategic border management tasks

2.4.6 Outcome Document: A Web-based Java Framework for Cross-platform Mobile GIS and Remote Sensing Applications

Citation
Tsou, M.H., Guo, L. and Howser, T. 2005. A Web-based Java Framework for Cross-platform Mobile GIS and Remote Sensing Applications. *GIScience & Remote Sensing*, 42(4): 333-357.

PDF Document
Tsou-2005-GISRS.pdf

Abstract
A cross-platform Web-based Java development framework for Mobile Geographic Information Systems (Mobile GIS) and remote sensing (RS) applications is introduced for the notebook computer, Pocket PC, and mobile phone platforms. Using these platforms, Java software

technology is examined for its cross-platform utility in the development of various Mobile GIS and map/image display functions. The three case studies developed with Java 2 Standard Edition (J2SE), Java 2 Micro Edition (J2ME), and Mobile Information Device Profile (MIDP) are examined within the context of mobile GIS. Significant challenges in developing cross-platform Mobile GIS applications are also discussed. These obstacles include heterogeneous operating systems, different wireless communications protocols, low bandwidth network connections, and the general lack of usability.

Conclusion and Future Work

Reliable geospatial information management tools with visual and analytical capabilities are in great demand to maximize the use of geospatial data in facilitating decision making processes (Gahegan, 1998; Brown, 1999). With the rapid development of wireless and mobile technology and applications, comprehensive Mobile GIS applications are requested by many GIS and RS users. With the arrival of high bandwidth wireless mobile networks, these networks have been identified as possible data transport mechanisms for Mobile GIS applications. Challenges still remain for the development of robust and user-friendly Mobile GIS applications.

Heterogeneous operating systems of different mobile devices, including the Windows CE OS, the PalmOS, the Symbian OS, and the Java Phone OS, are additional hurdles to development of robust cross-platform applications. A single Mobile GIS application developed for several differing platforms and operating systems can be extremely expensive and time consuming. Each individual platform and OS may require a nearly complete rewrite of programming code in order to duplicate application functionality and specified requirements. To address this issue, the GIS software industry and mobile computing device vendors need to establish a community-based standards organization for the future development of Mobile GIS applications. Presently, OpenGIS Location Services (OpenLS) specifications by the Open GIS Consortium (OGC, 2003a) offer a good example for setting mobile application standards. In this instance, the organization addresses Location-Based Services (LBS) standards for Mobile GIS and other applications. They have specified the adoption of XML-based Abstract Data Types (ADT) and the GeoMobility Server for cross-platform and cross-device functionality (OGC 2003a, 2003b). Similar standards initiatives need to be pursued for field-based Mobile GIS and mobile RS applications.

Another consideration is the inadequate bandwidth of current wireless communications technology. This limits the feasibility of the development of GIS and RS applications due to their relatively large data sizes. Current wireless technology, in the best-case scenario, can only provide up to 1 Megabit per second of data transfer via an advanced cellular mobile phone network like CDMA or newer 3G systems. Most GIS and RS applications require high-speed network connections since GIS and RS imagery data are routinely 10–500 MB in size. Because of these considerations, and the general lack of supporting application tools and mobile communications infrastructure, it is currently difficult to access available GIS/RS data. Pocket PCs and similar devices are in a more advantageous situation when it comes to bandwidth considerations due to their ability to use high-speed wireless protocols and devices such as IEEE 802.11 (Wi-Fi) and Bluetooth. IEEE 802.11 technology is very robust and well utilized, and can enable wireless data transfer at a rate of 11 megabits per second to 54 megabits per second in the

ideal situation. WiMAX is an emerging IEEE 802.16 standard for broadband wireless wide-area network (WWAN) or Metropolitan area network (MAN) applications. WiMAX can provide a larger coverage of service area than Wi-Fi. Its communication signals can cover a range of 4–6 miles (up to 20 miles for the long-distance setting). To address the wireless communication issue, the development of Mobile GIS applications make it possible to robustly handle erratic signal coverage, with features such as download restart, synchronization, and continuation after line drops. The ideal solution is to provide seamless communication merged from cellular mobile coverage and the Wi-Fi/WiMAX combination.

Another challenge is the usability of Mobile GIS and remote sensing applications. Most Mobile GIS devices are constrained to a platform with a limited visible screen area, memory, computational power, and communications ability. Much research must go into human factors and GUI design. Different platforms may require GUI modifications to best serve its target user needs. Some solutions can include utilization of specialized input systems, including the touch-sensitive display panels on Pocket PCs and Tablet PCs, or voice-recognition technology on Pocket PC and mobile phone devices. Recent innovations in consumer-grade GPS automobile navigation systems may offer hints to solutions for addressing these issues in Mobile GIS applications.

Potential applications of Java framework–based programs for the display and manipulation of GIS and RS data were examined. Visual and analytical functions of applications developed for three different hardware platforms were analyzed and discussed. These application tools examined how users can interactively access, navigate, and explore visual RS and GIS data over mobile computing devices. Although the development of Mobile GIS and RS applications is at its infancy, there is great potential for Java framework-based analytical tools in several application areas including environmental monitoring, natural resources management, emergency management, and homeland security. Mobile GIS data collection and geospatial analysis over Internet connections can result in cost savings, the reduction of manpower requirements for field monitoring tasks, and encourage the sharing of analytical tools.

Other alternative approaches for Mobile GIS applications can be combined with the Java platform. Scalable Vector Graphics (SVG) and mobile web services are two promising future technologies for mobile GIS and remote sensing. SVG is an XMLbased, two-dimensional vector graphics media format specified by the W3C in 2001 (version 1.0) and in 2003 (version 1.1) (W3C, 2003). There are three types of SVG probiles: SVG Full, SVG Basic, and SVG Tiny. SVG Full is suitable for desktop or laptop PCs. SVG Basic (smaller than SVG Full) is designed for Pocket PC or PDAs. SVG Tiny is designed for mobile phones. The advantage of mobile SVG (Basic and Tiny) compared to other graphic formats is that it can provide a compact, multimediaenabled vector display format. SVG images are scalable and dynamic, and can be used within the Java platform. For example, SVG Tiny can become one of the major display formats for J2ME applications.

Mobile web services are an extension of general web services that are built upon XML; Simple Object Access Protocol (SOAP); Universal Description, Discovery, and Integration (UDDI); and Web Services Description Language (WSDL). Mobile web services can combine multiple

functions and customizable information provided by web service providers for different mobile applications and users. The advantage of adopting web services for mobile GIS application is that web services can provide flexible combination of multiple web computing techniques with modern enterprise GIS architecture. The contents of mobile web services include short messaging services (SMS), multimedia messaging services (MMS), and location-based services (LBS). Most mobile web services rely on server-side computing power significantly. For mobile GIS or LBS tasks, web services work like client-side terminals, with more flexible choices of GIS functions provided by remote web servers rather than running GIS functions locally. This is quite different from Java platform applications, which utilize client-side (mobile devices) computing power for major GIS works.

To summarize, future development of Mobile GIS and RS applications should entail better user interface and human-factor design, and development of more advanced analytical tools and capabilities, including dynamic sketching, geometric calculation, vector overlay, and image feature classification. With its features and capabilities, the Java framework may offer a robust and appropriate cross-platform solution to facilitate the development of the next generation of Mobile GIS and RS applications and tools. Moreover, the cross-platform nature and accessibility of applications developed within the Java framework may broaden the scope and appeal of Mobile GIS, RS, and other geospatial tools and applications for the public at large.

2.4.7 Outcome Document: Bridging the Gap: Connecting Internet-based Spatial Decision Support Systems to the Field-based Personnel with Real time Wireless Mobile GIS Applications

Citation

Tsou, M.H. 2006. Bridging the Gap: Connecting Internet-based Spatial Decision Support Systems to the Field-based Personnel with Real time Wireless Mobile GIS Applications. In *Collaborative Geographic Information Systems*, S. Balram and S. Dragicevic (Eds.), pp. 316-339 (Idea Group, Inc.).

PDF Document
Tsou-2006-Bridging the Gap.pdf

Abstract
Internet GIS provides a collaborative communication environment for sharing data, information, and knowledge. Mobile GIS can add both geospatial information and global positional systems (GPS) coordinates from remotely located field-based personnel to spatial decision support systems (SDSS). By adopting broadband wireless telecommunication technology for connecting Internet GIS and mobile GIS devices, decision makers can gather near real-time information from field personnel and, equally quickly, distribute updated information back to the field. This chapter introduces a collaborative GIS prototype that demonstrates an interoperable framework for combining Web-based GIS technologies and wireless mobile GIS applications. The integrated framework provides real- time or near real-time GIS data update functions (such as

adding new spatially located map features or GPS tracking locations) between mobile GIS devices and Internet GIS servers. Although these real-time GIS functions can be very important during time-urgent emergencies, they can be equally beneficial and highly cost effective during routine field activities.

Conclusion

On December 26, 2004, people from around the world began to realize the power of nature, and that natural disasters are a daily risk we must address. Following a massive 9.0 earthquake in the Indian Ocean, a horrifying tsunami destroyed the coastline areas of 11 countries, and caused a massive number of deaths (over 150,000). Many geographers and GIS professionals asked themselves a fundamental question: "Why did such a tragedy happen in these areas and could we have responded better?" What if these areas have an advanced collaborative, Web-based emergency response system?

A Web-based spatial decision support system could assist the local governments and emergency response teams in identifying potential threat areas so critical "hot zones" could be quickly and accurately identified. A Web-based GIS data portal could be used to rapidly generate the most effective evacuation routes and emergency plans during natural hazard events including wildfires, flooding, and tsunami. Real-time or near real-time GIS could also assist public policy officials, firefighters, and other first responders with identifying areas where their forces and resources are most needed. Many people agree that an integrated and comprehensive geographic information system (GIS) is an essential component for successful disaster prevention and mitigation. Clearly, collaborative GIS could become a vital technology to save lives and assist in recovery.

This paper gives a brief introduction about the capability of collaborative GIS. It is important to educate people and organizations on the utility of collaborative GIS technology, and why it is to their benefit to adopt the technology in their daily lives. As always, the cost of disaster recovery and mitigation is much more expensive than the cost of early prevention using systems such as a Web-based SDSS.

In order for collaborative GIS to be most effective for natural hazard prevention and response purposes, the system should be incorporated into the regular planning activities; training; and exercises conducted by local, regional, and federal government officials and agencies. An example of the routine use of an SDSS in improving emergency response would be the application of real-time SDSS by local governments to monitor the roadway traffic, air quality, and E-911 responses. Monitoring daily roadway traffic can quickly be transformed into monitoring evacuation routes or routing emergency relief aid. Without training, familiarity, and exercises, any emergency response tool, including a real-time SDSS, may not be effective to an official, organization, or government when an actual hazard situation occurs.

This chapter introduced a real-time Web-based spatial decision support system for use by decision makers and in situ agents to collect and process information via a secure intranet or encrypted mobile wireless networks to make better and timelier decisions. The goal of an integrated SDSS is to bridge the gap between traditional control-center-based spatial decision

support systems and field agents through the use of real-time wireless mobile GIS applications and their benefits to decision making.

2.4.8 Outcome Document: Spatial Decision Support Services Enhance Homeland Security

Citation
Tsou, M.H., Stow, D. and J. Kaiser. 2006. Spatial Decision Support Services Enhance Homeland Security. *GeoIntelligence,* Mar/Apr 2006:18-23.

PDF Document
Tsou-2006-GeoIntelligence.pdf

Abstract
The purview of the U.S. Department of Homeland Security includes the prevention and mitigation of terrorist attacks, recovery from natural hazards, and response to industrial hazards from chemical explosions, nuclear powerplant meltdowns, and train wrecks. Using spatial information technologies to enhance collaboration between local and federal government agencies, prevention and mitigation tasks can be accomplished in a more timely and efficient manner, thereby reducing the nation's vulnerability to such events. Here, the authors introduce a design for a fully integrated cyber infrastructure and a technology framework to accomplish the major tasks of homeland security

Conclusions
On January 17, 2006, Homeland Security Secretary Michael Chertoff announced plans to strengthen security at U.S. borders. "To strike the right balance between security and facilitation," said Chertoff, "we have to incorporate 21st century technology and innovation."

Indeed, we need to use state-of-the-art geospatial technology to provide a reliable, sustainable solution for maintaining homeland security. Innovative technologies (high-speed wireless communication, geospatial information services, Web-based mapping tools, Web services) can be applied to various tasks of homeland security and sharing critical information among decision makers and the public.

Although we cannot control natural disasters, we can greatly improve the way we plan for and respond to emergencies, whether natural or terrorist-induced, through the expanded use of geospatial technologies, satellite imagery, and wireless communications integrated into spatial decision support services developed at the local, regional, and national levels. These are some of the key 21st century technologies Secretary Chertoff refers to in his speech. How we prepare for and respond to emergencies is an indication of how seriously we take our homeland security obligations. The technology framework for the BSDSS can greatly improve our emergency response capabilities.

2.4.9 Outcome Document: Mobile GIServices Applied to Disaster Management

Citation
Tsou, M.H. and Sun, C.H. 2007. Mobile GIServices Applied to Disaster Management, Book chapter in *Dynamic and Mobile GIS: Investigating Change in Space and Time*. (edited by Drummond, J, Billen, R., Forrest, D. and Joao, Ed. 2006. published by CRC Press, Taylor & Francis. (Innovations in GIS book series), pp. 213-236.

PDF Document
Tsou-2007-Mobile-GIServices.pdf

Introduction
Disaster management (or emergency management) is unique among GIS applications because it deals directly with loss of human life and property damage. In September 2005, the tragic event of Hurricane Katrina in the US demonstrated how important disaster management is. While the comprehensive implementation of disaster management systems can save thousands of people's lives, poorly implemented disaster management can of itself cause significant casualties, property damage and economic loss when the disaster happens.

On December 26, 2004, another example of poor disaster management was recognized after a massive 9.0 earthquake in the Indian Ocean. A horrifying tsunami destroyed coastline areas of 11 countries and caused an unbelievable number of deaths (over 150,000). People from around the world began to realize the power of Nature and how devastating hazards and loss can occur by underestimating her power. Some news reporters from the National Public Radio (NPR) in the US commented that if these countries around the Indian Ocean had had a tsunami early warning system (such as the Pacific Tsunami Warning System used by the US and Japan) hundreds of thousands of people would have been saved from the tsunami. However, the authors of this chapter disagree with this statement because a single tsunami warning system is not sufficient for the establishment of comprehensive disaster management. This chapter argues that what is really needed is an integrated mobile and distributed GIService, combined with the early warning systems, to support disaster management, response, prevention and recovery.

To create a comprehensive disaster management system, our society needs to rely on advanced geospatial technologies and services. Mobile GIS is one of the most vital technologies for the future development of disaster management systems. Mobile GIS and mobile Geographic Information Services (Mobile GIServices) extend the capability of traditional GIS to a higher level of portability, usability and flexibility. Mobile GIS are integrated software and hardware frameworks for the access of geospatial data and services through mobile devices via wireline or wireless networks (Tsou, 2004). The unique feature of mobile GIS is the ability to incorporate Global Positioning Systems (GPS) and ground-truth measurement within GIS applications.

This chapter introduces a new term, "Mobile GIServices", which describes a framework to utilize Mobile GIS devices to access network-based geospatial information services (GIServices). Mobile GIServices can be adopted in various GIS applications and scenarios,

including car navigation systems, utility management, environmental monitoring and habitat protection tasks. Disaster management and emergency response are one of the most popular domains in the recent development of Mobile GIServices.

For example, mobile GIServices can combine GPS and satellite images to assist the local government and emergency response teams in identifying potential threat areas. So critical "hot zones" can be immediately created. Near real-time spatial analysis models supported by GIS could be used to rapidly generate the most effective evacuation routes and emergency plans during natural hazard events, including wildfires, floods and tsunamis. Wireless Internet-based GIS could also assist public policy officials, firefighters and other first responders with identifying areas to which their forces and resources should be dispatched. To accomplish these goals, it is important to introduce these new mobile GIServices technologies to emergency management personnel and related organizations. Also, emergency managers and first responders need to realize both the advantages and the limitation of GIS technologies in disaster management.

In the US, the percentage of agencies that used computers as tools for emergency operations (such as 911 or emergency calls, ambulance dispatch, evacuation procedures or rescue services) was 54.2% in 2001. The percentage using emergency management software (such as GIS or Management Information Systems – MIS) was 26.6% (Green, 2001). Although software usage has increased in the last few years, some emergency managers and staff are still reluctant to adopt computers and GIS for their main tasks (based on the authors' own experiences). One of the major obstacles is the concern for system portability and reliability. Traditional GIS are not considered portable by first responders (such as local police officers, fire fighters and emergency medical personnel who can arrive first and take actions to rescue people and protect property). Emergency managers also worried that loss of electrical power during a disaster might cause the whole computer system to breakdown.

The recent development of Mobile GIS and Mobile GIServices might solve these problems, as proposed in this chapter, by providing their own independent power supply systems (batteries and Uninterruptible Power Supply - UPS) and having a great portability (cellular phones, Pocket PCs, etc.). In addition, this chapter discusses how the new wireless communication technologies, such as 4th Generation (4G) cellular phone systems, Wi-Fi, and Wi-MAX techniques, might further improve the capability of Mobile GIServices and support comprehensive information services for disaster management.

This chapter will first introduce the disaster management framework for mobile GIServices (Section 12.2) and then recent advances in mobile GIService technology (Section 12.3). The discussion will focus on disaster management in three categories: emergency preparedness, emergency response and disaster recovery.

Next, the Taiwan Advanced Disaster Management Decision Support System (TADMDS) will be introduced as a showcase of the integration of Mobile GIServices with Web-based GIServices (Section 12.4). Finally, this chapter will conclude in Section 12.5 by highlighting the current limitations and possible future directions of Mobile GIServices technology.

Conclusions and Future Developments

Disaster management is a complex domain of human activity involving multiple agencies and stakeholders, a collaborative approach utilizing state-of-the-art Mobile GIServices can facilitate a comprehensive and functional disaster management plan. This chapter introduced the basic components of Mobile GIServices and their potential disaster management role in three main phases: preparedness, response and recovery. The GIS industry has started focusing on Mobile GIS applications and the development of mobile hardware/software (Peng and Tsou, 2003), such as ESRI's ArcPAD, Mapinfo's MapXtend, and mobile Google map (Google Inc., 2005). However, there are still some major impediments in the development of Mobile GIServices.

The first impediment is the lack of comprehensive user interface designed specifically for Mobile GIServices. Most current mobile GIS software still follows the legacy concepts of desktop GIS interfaces. The tiny, sensitive stylus pen and the small on-screen keyboard input method are not the right choice for Mobile GIServices in the emergency context. Direct voice commands and an easy, touchable screen simply used by human fingers (that may be wearing gloves) are more appropriate for emergency responders and in-field workers (see Figure 12.10).

The second limitation of current Mobile GIServices is the lack of real-time data collection and distribution mechanisms. It was difficult to verify the accuracy of submitted geospatial data from fieldwork. Currently, a GIS professional has to manually convert the data submitted from field workers to the Web-based GIService framework. Some predicted advances in Web Services technologies and improvement in distributed database functions might solve these technical problems in the future. However, it is always dangerous to rely on automatic data conversion without verifying the data accuracy and data quality.

The third impediment is the integration of spatial analysis and GIS modeling into Mobile GIServices. Many emergency tasks and disaster management works will need advanced GIS analysis functions that required significant computing power and computer memory. Most mobile GIS devices are tiny and only have very limited computing capability. The pre-processing and post-processing time for spatial analysis and remote sensing images might prevent the adoption of Mobile GIServices for real-time response tasks due to the hardware limitations. One possible solution is to send the complicated GIS model and spatial functions via the Internet to remote GIS engine services. Then, the analysis results will be sent back to the Mobile GIS devices via the network.

The final issue is the lack of alternative display methods for Mobile GIServices. Since most mobile GIS devices are small and fragile, emergency responders and managers might be reluctant to use small screens on Pocket PC or cellular phones to share their maps with others. One possible alternative is to print out paper maps directly from Mobile GIS devices since paper maps are easy to carry and there will then be no need for batteries in the field. It would be useful if users could print paper maps directly from their Mobile GIS devices via wirelessly portable printers or from built-in printer inside a Pocket PC or a notebook computer.

In summary, this chapter introduced an integrated Mobile GIServices framework that can provide comprehensive services for disaster management tasks. The chapter has argued that Mobile GIServices are a very promising field with very high demands from both field-based workers and the GIS vendors. With the progress of new wireless communication technology and GPS techniques, Mobile GIServices can help to monitor the dynamic changes in the real world and provide vital information to prepare and prevent natural hazards or human-made disasters. Hopefully, with the efforts from GIS professionals and GIS developers, the advancement of dynamic and mobile GIS research will protect people from various hazards in the future and improve their quality of life.

2.4.10 Outcome Document: Integrating Real-time Mobile Computing and Web-based GIS for Campus Security Management

Citation
Yang, D.D. 2004. Integrating Real-time Mobile Computing and Web-based GIS for Campus Security Management. Master Thesis. San Diego State University.

PDF Document
Yang-Dawn'sThesis-8-21-2004.pdf

Introduction
Today, at the dawn of the 21st century, public and private sectors have high demand for mobile data collection and real-time mapping in the field. Mobile GIS provides possible solutions in many emerging applications. Mobile GIS provides flexibility to users for collecting data or processing tasks in real-time arbitrary times and locations. Through wireless communications, mobile computers in such applications connect to the dispatch centers or other mobile computers for real-time collaboration purposes.

Today, the common practice is downloading the data in the morning from the corporate office into a mobile computing device such as laptop computer or Pocket PC and taking the mobile device to the field. The field crew then works on editing and validating the data in the field. At the end of the day, the updated data are uploaded to the corporate content server. In the future, as the bandwidth of wireless networks improves, real-time communication between fieldwork and the office content server is foreseeable.

GIS is a data integrator which allows different databases to be overlaid using geographic location as the integrating mechanism. GIS is 'layered' which allow the user to view different layers to determine spatial relationships that exists. GIS maps are completely interactive. Users can "zoom in" and "zoom out" on a selected feature and view attributes, track real-time events or create report with selected features.

Mobile GIS is GIS on a mobile device. Today, mobile GIS is typically being used for field data acquisition and validation, real time incident investigation and site analysis, real time work order management and dispatch, and real time responses to customer service requests etc.

Conclusions
This research showed there is a great potential for mobile GIS applied for Campus Security Management. The Mobile GIS can significantly reduce the high cost and intensive labor associated with field monitoring and data collections. Although San Diego State University Campus Security Management provided the sample test bed for this research, the potential users of mobile GIS extend far beyond a campus.

2.4.11 Outcome Document: The Integration of Grid-enabled Internet GIServices and Geographic Semantic Web Technologies

Citation
Zhang, T. and Tsou, M.H. 2005. The Integration of Grid-enabled Internet GIServices and Geographic Semantic Web Technologies. *Geographic Information Science,* 11(1): 15-23.

PDF Document
Zhang_Tsou-2005-JGIS_final_short.pdf

Abstract
This paper presents a new framework for Grid-enabled GIService web portals to facilitate the building of high-level intelligent Internet GIServices. The five-tier architecture can provide advanced semantic search and query functions for distributed GIServices by combining Grid computing, Semantic Web, and software agent technologies. The design of the web portal user interface with software agents can help end users combine and integrate computing power with geospatial data and services. Geospatial ontologies are incorporated into the framework by using geographic web ontology language (G-OWL). Intelligent software agent (GeoAgent) techniques are used to automate the procedures of geo-spatial data, search, retrieval and processing. The proposed Internet GIService architecture will provide a blue print for the establishment of Grid-enabled Internet GIServices and will help the GIS community to identify potential technical challenges for the implementation of intelligent Internet GIServices.

Conclusion
This paper introduces an integrated Grid-enabled and semantic-based Internet GIService framework which can offer intelligent GIServices with querying, fetching and coordinating capabilities in distributed network environments. The integration of Grid-enabled GIServices, Semantic Web, and software agent technologies was formalized in a five-tier framework designed specifically for the next generation of Internet GIServices. To achieve the full potential of Internet GIServices, the GIS community needs to collaborate with geodata providers, web services designers, and the public/private sectors. The integrated five-tier Internet GIService architecture proposed in this paper can be a pioneer endeavor to build the foundation for

distributed Internet GIService. This paper has investigated the theoretical and technical difficulties in the development of integrated Grid-enabled and geospatial ontologies based GIService network.

Within this new Internet GIService architecture, we can address the two big problems we discussed at the beginning, communication speed and interoperability. The performance of Internet GIServices will be greatly enhanced by Grid computing thus the complicated GIS data and tasks will be distributed across the network more efficiently preventing the problem of communication speed. Geographic Semantic Web, which standardizes all the communications between users and distributed GIServices, will make the transfer of information and knowledge transparent on the Internet. The integration of all kinds of data and analysis services becomes possible in this way. Software agents can handle the communicating tasks in the entire framework (e.g. interpretation of user's input, the searching and locating of GIServices, parsing and formalizing user requests and computational results etc.). In summary, the integration of Grid computing, Semantic Web, and software agents will provide a new direction for the future development and performance improvement of intelligent Internet GIServices. There are other complementary approaches that can also improve the performance of Internet GIServices. For example, Yang et al. [30] discussed several innovative web techniques to improve the performance of Web-based GIS. These methods include a pyramid technique and harsh index, cluster and multithread, caching and dynamic data request, binary format and compression which work in both server and client side to enhance data accessing efficiency. We believe that all these web techniques can be integrated into our five-tier architecture to achieve better Internet GIServices performance. Hopefully, by integrating with these innovative web technologies, the development of Internet GIServices will provide better geospatial services for our end-users and help them accomplish their geospatial analysis tasks more effectively.

2.4.12 Outcome Document: Developing Grid-enabled Internet GIServices to Support Geospatial Cyberinfrastructure: A Pilot Study in Accessibility

Citation
Zhang, T. 2008. Developing Grid-enabled Internet GIServices to Support Geospatial Cyberinfrastructure: A Pilot Study in Accessibility. Doctoral dissertation. San Diego State University.

PDF Document
Dissertation_Tong Zhang.pdf

Abstract
A geospatial cyberinfrastructure provides coordinated geographic information services (GIServices) to enable scientists to conduct advanced geospatial research effectively and efficiently. The establishment of a geospatial cyberinfrastructure facilitates the development of innovative geospatial analysis tools, the interoperability of GIServices, and the advancement of GIServices.

This research develops a four-tier GIService framework for the next generation of Internet GIServices in order to support a geospatial cyberinfrastructure. This framework can provide a solution for solving the technical challenges of GIServices. Performance and integration are the two major technical challenges of GIServices. High performance computing resources can support more powerful Internet-based geocomputation services. Integration of heterogeneous GIServices can enhance the usability of Internet-based GIServices. Concerning geospatial cyberinfrastructure, integration and performance are the major foci of this dissertation. An accessibility analysis pilot study is used to demonstrate how performance and integration can be enhanced by this research's new cyberinfrastructure framework.

The advantages of the proposed four-tier framework over the typical three-tier client/server Internet GIS framework are demonstrated by a grid-enabled accessibility analysis service via a Web portal. The Web portal demonstrates the practical procedures of integrating geospatial resources and delivering high-level GIServices via cyberenvironments. The methodology compares the performance of Internet-based GIServices using different computing resources and configurations, such as parallelized versus serial algorithms, and wide area grid versus local PC clusters. The detailed analysis of these different computational settings contributes to a deeper understanding of the strategies for improving Internet GIServices in a geospatial cyberinfrastructure environment.

This research demonstrates that performance improvement and service integration can be achieved by implementing the new four-tier Internet GIService framework. In addition, this research identifies potential benefits in providing powerful geocomputation services, simplified data analysis portals, and collaborative problem solving environments for transportation planning research activities. Based on the practical experience of implementing a prototype, this research lays a technical foundation for subsequent endeavors toward the construction of a future geospatial cyberinfrastructure.

Summary
This dissertation focuses on two critical issues of geospatial cyberinfrastructure, performance and integration for the next generation of Internet GIServices. A new grid-enabled Internet GIService framework is proposed and demonstrated. The framework is partially implemented in a transportation accessibility analysis Web portal prototype. The experimental results demonstrate that Web portals can deliver high performance GIServices and integrate various GIServices to provide complex GIS analytical services. The significance of this research is three-fold: 1) A new comprehensive four-tier grid-enabled Internet GIService framework for the future development of geospatial cyberinfrastructure is proposed; 2). We developed an integrated high performance Web portal prototype and conducted a series of experiments to investigate the performance and integration issues. The practical experience gained during the development and experiments are useful for future geospatial cyberinfrastructure; 3). The implementation of high performance transportation accessibility analysis proves the feasibility of our framework and technical strategy. This works as an example to encourage the use of emerging cyberinfrastructure and Internet GIService technologies in other geospatial applications.

The advantages of our new framework are summarized in section 6.1. Compared to other research on Internet GIS and high performance geocomputation, we explore the technical potentials for geospatial cyberinfrastructure as a whole while emphasizing the analysis of high performance GIServices in grid-enabled Web portal environments. The data and analysis algorithms we chose to test are intractable in nature but can be run with desktop computers. The driving force of developing and testing the prototype leans the "middle-size" geospatial problems which are difficult to solve in real-time or near real-time. However, grid computing plus grid-enabled Web portals provide an alternative approach to real-time Internet-based analytical or modeling GIServices. We believe there are a large number of geocomputation models that can be good candidates to apply our methods to achieve significant performance enhancements. Real-world common GIS applications frequently encounter the dilemma that it is too slow to run GIS analysis services (some are time-critical) using a desktop or GIS server while it is also too time-consuming or difficult to run them on a grid platform. Our research aims at this problem and proposes a solution of combining emerging technologies in Web portals to handle common GIS analysis services. The experiments demonstrate the feasibility, scalability, effectiveness and efficiency of our methodology with an intuitive friendly interface.

Our framework and technical methodology are scalable for application developers. Application developers can simply integrate various small grid-enabled GIServices and package them in Web portals. Grid-enable Internet GIServices can be developed and hosted by service developers. With mature geospatial middleware, and GIService discovery and composition tools, the vision of a geospatial cyberinfrastructure can become a reality. Our framework and technical methodology separate the roles of service developers and portal administrator. This strategy is highly flexible for application developers and end users to build the best-of-breed systems based on performance, availability, service quality, and user needs.

Compared to other research on Internet GIS or high performance geocomputation, our research has the following unique features:

1. It focuses on common Web mapping and analytical services rather than special domain-oriented problems such as GISolve (Wang 2006).
2. It investigates the possibility of implementing a complete grid-enabled GIS analytical service, from the data searching to result visualization.
3. It addresses the two key issues, performance and integration, while presenting a comprehensive discussion on geospatial cyberinfrastructure.
4. It implements the prototype with a hybrid open source and commercial method.
5. It demonstrates a complete solution for high performance Internet GIService which not only proposes theoretical framework and technical plans, but also implements a prototype and conducts experiments along with an in-depth discussion.

2.5 Apprehension Demographics, Data Mining and Geospatial Visualization

The interdiction demographics component of this project links and analyzes characteristics of migrants apprehended at the border with the characteristics of the localities of origin in Mexico from which they came. From these links, the project identifies factors pushing immigrants to

U.S. and relates information about the individuals apprehended and their geographical paths to the border.

The SDSS architecture task involves conducting a user needs analysis, evaluating the suitability of decision support methods, and developing prototype software component specifications to develop models for predicting geographic patterns of illegal immigration across the border.

2.5.1 Key Accomplishments

Interdiction Demographics

In the interdiction demographics research we make use of a unique unduplicated file of people detained at or near the border by the US Border Patrol during the years 1999 through 2006. By focusing especially on the population aged 20-34, we are able to create a migration propensity index, which is the ratio of detainees from each state in Mexico to the population aged 20-34 in that state. The analysis of this index confirms the few other sources of information suggesting that migration from Mexico to the United States is increasingly occurring from the more southern, indigenous states. A multiple regression analysis of the migration propensity index and state-level variables finds that the death rate from accidents and violence among men aged 20-34 is the single most important predictor of a state's migration propensity index (Weeks et al., 2009). This is related to a variety of factors indicating that migrants are coming from states with the poorest economic infrastructure.

Data Mining and Geospatial Visualization

The Data Mining Project Team developed models for predicting geographic patterns of illegal immigration across the border. In addition to physical parameters such as slope, landuse, vegetation, road networks and climate, the project team created predictive layers including trail density, border enforcement posture, fences, and smuggling measures.

The team developed spatio-temporal data mining tools. The tools implement point-pattern spatial data statistics including global and local Moran's I, global and local G*, and K-functions and allow users to apply them in order to detect spatio-temporal clusters of origin areas in Mexico. The origin areas are either states in Mexico or municipios representing the home areas of illegal immigrants apprehended during the time interval 1999 – 2006. The original data used by the tools come form the ENFORCE data set. There are also spatial statistics that can be used to test whether or not the observed spatio-temporal are random or systematic (statistically significant).

The tools (implemented with Java technology) allow computing in a table and simultaneously visualizing on a map, clusters of origin areas in Mexico. Using the time-series data for apprehensions between 1999 and 2006 the tool allows visualizing changes in the distributions and patterns of municipios, which had either above average or below average share of people leaving for the US border. The user is able to select a specific sector of the US-Mexico border, select any two years, and visualize changes between the selected two years in the pattern of origin areas with respect to this particular border sector.

The benefits from this research are methodological and practical. The methodological benefits include the successful application of advanced cartographic visualization tools combined with data classification techniques to a large-size geographic datasets. The practical benefits include the detection of patterns of movement of illegal immigrants from Mexico into the US along the San Diego County section of the border. Results extend our knowledge on how to effectively use exploratory data visualization methods combined with spatial data mining techniques to detect and exploit spatio-temporal patterns derived from large USBP apprehension datasets. Implementation of such methods by the Border Patrol should improve intelligence analyses and antiterrorist field operations.

2.5.2 Outcome Document: Organized Visual Data Mining of Immigration Propensity

Citation

Fraley, G., C. Giovando, and P. Jankowski. 2008. Organized Visual Data Mining of Immigration Propensity. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

PDF Document

MPI_Municipio_REASoN_report.pdf

Introduction

When the United States Border Patrol (USBP) apprehends individuals who have illegally entered the United States from Mexico, pertinent information is recorded and entered into the USBP's ENFORCE Integrated Database (EID). The EID contains attributes on location of birth and apprehension, among others. Thus, an analysis of origin and destination is feasible. Understanding the origin-destination patterns of USBP apprehensions over time can aid characterization of push and pull factors for immigration, assist evaluation of enforcement practices, and inform policy decisions.

In order to analyze immigration flows, an index of immigration propensity was calculated for each Mexican state and municipio with respect to each USBP sector. Changes over time in municipio immigration propensity were calculated. State level immigration propensity is presented using maps animated over time and by sector. Municipio changes were then examined using global and local spatial clustering statistics. Clusters of similarly or dissimilarly changing municipios are discovered and organized visually using a custom software tool.

Conclusions

The Migration Propensity Index (MPI) can be calculated and mapped using map animation to visualize changes in the origin-destination dynamics of illegal immigration from Mexico to the US. In the animated map developed in this project the origins are represented by Mexican states and destinations are represented by the sectors of the US-Mexican border. In order to detect and visualize statistically significant spatio-temporal clusters of origin areas at a larger geographical scale than Mexican states the MPI was computed for the municipio-level data. The temporal changes were conceptualized and represented as the pair-wise differences between combinations

of years from the 1999 – 2006 time period. The global version of Moran's I statistic was tabulated for each sector and included all feasible combination pairs of years. The statistically significant combinations can be analyzed further by displaying a clustering pattern of municipios that show either a similar change in the MPI values for the selected pair of years or the dissimilar change. The future steps may include the analysis of statistically significant clusters in terms of finding factors that may explain why some municipios are different from others in terms of their MPI values.

2.5.3 Outcome Document: Spatial Knowledge Discovery Through an Integration of Visual Data Exploration with Data Mining

Citation

Giovando, C. and Zhang, T. 2005. Spatial Knowledge Discovery Through an Integration of Visual Data Exploration with Data Mining. In *UCGIS Summer Assembly*, June 2005, Jackson Hole, WY.

PDF Document

01_Giovando_UCGIS2005_Paper.pdf

Abstract

The use of multi-dimensional abductive inference has been a challenge for geographers who are interested in discovering research hypotheses from data. This and other exploratory data mining techniques have attracted much attention and hype as spatial analysis tools for scouring large databases in search of interesting spatial data patterns. Progress in data mining, spatial statistics, and visualization algorithms has also created a challenge in choosing the right set of techniques and tools for data analysis.

In this paper we describe one approach to choosing abductive inference techniques dealing with the real-world problem of discovering transboundary migration patterns. The approach is based on the integration of visual data exploration with data mining algorithms. Data visualization leads to clues about data patterns, and the clues guide data mining searches.

The results of data mining are then visualized, leading to additional clues and more tangible research hypotheses. We present the application of the approach and discuss its potential for guiding the selection of data mining and visualization techniques for effective spatial knowledge discovery.

Conclusions

In this paper, we describe the integration of visualization and data mining for data analysis in a transboundary migration scenario. Visualization functions as a front-end tool for subsequent data mining. Also, visualization can validate intermediate results of previous data mining. The entire process of spatial knowledge discovery is evolving, due to the incorporation of more patterns and the elimination of errors and anomalies

Abductive inference is always a challenge when facing an ill-structured problem. We derive a framework for abductive inference by integrating visualization and data mining methods. This framework proves to be effective in our data analysis. We will proceed to verify current hypotheses using visualization and data mining methods.

2.5.4 Outcome Document: Analysis of Human Migration Behavior Along the U.S.-Mexico Border in the San Diego County Using an Origin-Destination Approach

Citation

Giovando, C. 2009 (Planned). Analysis of Human Migration Behavior Along the U.S.-Mexico Border Using an Origin-Destination Approach. Master's thesis. San Diego State University.

PDF Document

The thesis document is not complete nor available at this time.

Thesis Summary

The background idea for which this study was conducted is to better understand the phenomenon of illegal immigration from Mexico to the United States in terms of spatial and temporal context. Existing literature on this issue suggests that migration patterns change in time according to local condition at origin and patrolling strategies at the border.

The objective of this thesis is to identify what Mexican states have higher and lower sending rates of illegal immigrants to each of the ten Border Patrol sectors of the south west U.S.-Mexico border (Livermore, San Diego, El Centro, Yuma, Tucson, El Paso, Marfa, Del Rio, Laredo, and McAllen). Having identified those states, it shows whether a consistent trend in the period from 1998 to 2006 is visible.

Investigating at the higher spatial resolution of municipio data scale, this research identifies what areas in Mexico show time clusters of change in Migration Propensity Index (MPI) for the same 8 year period. MPI is a demographic index used to quantify the amount of immigration from a place to another. This index is calculated using census information and number of total apprehended immigrants originating from the same census area. The MPI method, although limited, provides the best representation of actual flows of immigrations given the information available and the geographic datasets that was possible to obtain.

The study also compares the results at state and municipio levels identifying spatial patterns in origin-destination routes. Trends at municipio level are identified and used to validate state level patterns. The global and local spatial autocorrelation index called "Moran's I" is used to identify clustered areas of municipios showing extreme changes in MPI over the 8 year time period. Values of census and socio-economic variables for selected municipios are used to explain these anomalies and find correlation between MPI and conditions of life at origin.

Overall the methodology adopted for this research relies on spatial statistics and demographic theorems, but this paper also describes methods on how data were acquired, the structure of each dataset and how it has been formatted and processed to become usable for the analyses.

The decision to proceed with the following methodology has come after several months of tentative methods for analysis of the ENFORCE dataset (containing Border Patrol arrest records) which have given no satisfactory results in terms of consistency and positive answer to initial research questions. Ultimately this methodology has provided a clear insight of how immigration changed in the 8 year period of this study.

The main outcome of this research is a set of maps representing MPI value changes in the period 1998-2006. Maps of state level MPI are used in geovisualization environments such as Google Earth for time series analysis of time-space patterns, showing clear trends in how migration has shifted from traditionally sending areas to more peripheral areas (Oaxaca, Guerrero, Chihuahua and Baja California). Global Moran's I analyses on time series highlight periods in which migration have increased in particular areas. These areas are further profiled using INEGI datasets of population and economy census variables to show where there is a significant correlation.

The MPI migration index proved to be an effective method for visualizing fluctuations in migration rate from areas in Mexico to the United States, both at state and municipio level. By improving the consistency in recording the place of origin in the ENFORCE dataset it will be possible to obtain even more detailed and homogeneous results.

2.5.5 Outcome Document: A Rough Set-Based Approach to Handling Uncertainty in Geographic Data Classification

Citation

Jankowski, P. 2007. A Rough Set-Based Approach to Handling Uncertainty in Geographic Data Classification. In: A. Moris and S. Kokhan (eds.), Geographic Uncertainty in Environmental Security. Springer Verlag, Berlin, pp. 75-87.

PDF Document

Jankowski_2007_Rough_Set_Approach_to_Classif.pdf

Abstract

The chapter describes how the Rough Set-based approximation of polygon classes with point-based elementary sets can lead to classification of point-in-polygon data patterns and consequently to knowledge in terms of classification rules, which are logical statements of the "if . . . , then. . . " type. The chapter also discusses properties of Rough Set-based approximation when indiscernibility relationship is substituted with dominance relationship due to preference ordered attributes in the classification table. Since the preference order attributes are common in spatial multiple criteria evaluation the presented approach has applications in spatial decision analysis.

Conclusions
The purpose of classifying data about illegal immigrants apprehended in the San Diego County sector of the US-Mexico border was to test whether or not a knowledge discovery approach based on rough sets would result in strong predictive rules. Such rules could theoretically link various common immigrant profiles, given by the values of condition criteria, with the classes of border crossing difficulty thus revealing possible border crossing preferences based on demographic and economic conditions. This reasoning is based on simple, yet unconfirmed theoretical arguments that would-be immigrants coming from better economic conditions have more resources at their disposal to choose border sectors that are less difficult to cross then those who come from poorer economic conditions. Similarly one can speculate that those with some experience abroad (usually in the U.S.) and previous apprehension experience will be more savvy in selecting their point of entry into the U.S. than those who lack such experience. These theoretical arguments were used in defining the preference order for condition criteria used in the classification. The lack of stronger and more discriminating rules than those derived with dominance-based rough set classification may result from three possible causes. First, theoretical assumptions behind the preference order of condition criteria may be wrong. Second, the quality of prior knowledge given by the condition criteria may be inadequate and it may require different conditions describing both socio-economic characteristics of immigrants and social networks facilitating their journeys to the U.S. Third, alternative partitions of the decision criterion domain can be used as decision classes. One can also use different decision variables based on alternative definitions of border crossing difficulty

2.5.6 Outcome Document: Who's Crossing the Border: New Data on Undocumented Immigrants to the United States

Citation
Weeks, J., J. Stoler, and P. Jankowski. Accepted March 2009. Who's Crossing the Border: New Data on Undocumented Immigrants to the United States. *Population, Space and Place*.

PDF Document
Who's Crossing the Border.pdf

Abstract
The majority of undocumented immigrants to the United States enter through the southern border and most are from Mexico. Researchers in the United States have been able to create estimates of how many unauthorized immigrants come from each country, but there has been little research on the geographic origins of immigrants from within Mexico. In this research we make use of a unique unduplicated file of people detained at or near the border by the US Border Patrol during the years 1999 through 2006. By focusing especially on the population aged 20-34, we are able to create a migration propensity index, which is the ratio of detainees from each state in Mexico to the population aged 20-34 in that state. The analysis of this index confirms the few other sources of information suggesting that migration from Mexico to the United States is

increasingly occurring from the more southern, indigenous states. A multiple regression analysis of the migration propensity index and state-level variables finds that the death rate from accidents and violence among men aged 20-34 is the single most important predictor of a state's migration propensity index. This is related to a variety of factors indicating that migrants are coming from states with the poorest economic infrastructure. We discuss the implications of these shifts for both receiving and sending communities.

Conclusions

In this paper we have used unduplicated counts of persons detained by the U.S. Border Patrol as a way of estimating who has been crossing the border from different states of Mexico into the US. Our data suggest that there has been a noticeable shift away from the "historic" states and the border states, and toward a larger absolute volume of migrants from the Mexico City metropolitan area, and from the states to the south of Mexico City. Thus, there appears to have been a noticeable shift in the geographic origins of migrants from Mexico in absolute terms, rather than maintain the historical pattern. This is consistent with data that Cornelius and his associates have deduced from their research in Mexico, and the pattern has also been observed by Mexican demographers (Anguiano Tellez 2003).

The comprehensiveness of the Border Patrol database allowed us to go beyond the absolute number of migrants per state, and to couple those data with demographic data from each state to calculate the propensity of people aged 20-34 in each state to migrate to the border. Since Estado de Mexico, for example, is a populous state, we would expect a large number of migrants to be from that state if all other things were equal. Michoacán, on the other hand, is only the tenth ranked state in terms of its population aged 20-34, and so its persistence as the leader in sending migrants suggests that people are leaving that state in disproportionate numbers. One explanation is clearly that historically it was, for a variety of reasons that may no longer matter, an early source of migrants and, following the model of cumulative causation, it has remained that way. Our migration propensity index showed that there were a number of states, including Michoacán and the other states highlighted by the MMP, that have been sending more migrants than would be expected just on the basis of how many young adults they have.

The National Population Council of Mexico (CONAPO) has created its own index of migration "intensity" for each state of Mexico, based on data collected in the sample portion of the 2000 Mexican census regarding family members who have migrated, and the comparison with our data, collected by the US government directly from would-be migrants, is instructive. The CONAPO study calculated the proportion of households in each state that (a) received remittances from a family member residing in the United States; (b) had at least one household member who migrated to the United States during the five years prior to the census and were still there at the time of the 2000 census; (c) had at least one household member who migrated to the US during the five years prior to the census and returned home to Mexico during that same time period; and (d) had at least one household member who had lived in the United States in 1995, but had returned to Mexico by the time of the 2000 census. These four variables were highly intercorrelated and so a principal components analysis was conducted to reduce them to a single score, which they called the Index of Migration Intensity. The Pearson correlation coefficient between our migration propensity index averaged over the entire 1999-2006 period and the

CONAPO Index of Migration Intensity was 0.76, suggesting that the state patterns we are observing are robust. An even better indication of the robustness is that the correlation is highest between the CONAPO index (which is based on the 2000 census) and our index based on 2000 detainees--.81. The coefficients drop monotonically over time, and the lowest correlation was with our 2006 detainee data (0.63), which is indicative of the changing nature of the migration flow from Mexico to the US. One of those changes, of course, is the fact that migrants are less likely to return to Mexico than was true in the past, but two of the four variables in the CONAPO index relate to return migration. If we look only at the percent of households who sent a migrant to the US during the five years prior to the census, the correlation with our index is even higher--.81 overall, and .85 for the year 2000, with no outliers among the states.

In examining the state-level factors that were most associated with our migration propensity index, we found that the most consistent predictor among those state-level variables available to us was the death rate from violence and accidents among men aged 20-34. The states with a higher propensity to violence also have a higher propensity for migration, although as we noted this is beginning to change. This is related statistically to several indicators of lower than average economic development. Not surprisingly, given the high correlation between our index and that of CONAPO, the latter's index of migration intensity was also most powerfully explained by the death rate from violence and accidents among men aged 20-34.

Our analysis of the state-level factors associated with the migration propensity index suggests the importance of the combination of demography and political economy. Lower levels of economic development and all of the problems that are associated with it are factors that contribute to migration, while high fertility plays a role in encouraging migration, probably because it creates a situation of too many young people chasing after too few local jobs. Although demographers are well aware of the push created by a redundant young population produced by high birth rates, this factor is rarely mentioned in migration analyses, so its emergence here as an important predictor is significant. At the same time, a lower than average employment rate among young men, even when taking the fertility effect into account, along with a generally unfavorable economic environment in a state are also statistically significant predictors of migration to the border. All of these factors suggest that people are leaving places where the situation is relatively bad, rather than migrating from places where the situation is better than average. Particularly noteworthy is the finding that the most rapid increase in the propensity to migrate is occurring in those southern states of Mexico dominated demographically by indigenous populations, and experiencing lower levels of infrastructure improvement than other states in Mexico. The state of Oaxaca seems to be leading edge least to the 1930s, household surveys from Oaxaca suggest that there was a clear upsurge in the 1990s (Cohen 2005). These southern states do not yet command the migration stream, but they represent an increasing fraction of all migrants. In the United States, the impact on local communities is that migrants may soon be less well educated, and less literate even in Spanish, than earlier migrants, reversing a trend toward gradually higher educational levels among migrants (see Marcelli and Cornelius, 2001), and thus potentially complicating local efforts to cope with their arrival. The evidence thus far suggests that indigenous Mexican migrants are most likely to seek jobs either in the service industry of the Los Angeles metropolitan area or in the agricultural sector of California's Central Valley, but there is anecdotal evidence of indigenous-language groups in

Illinois, New York, and Florida (Fox and Rivera-Salgado 2004). It has been suggested that this process "will require rethinking Mexican migration in terms of the diversity of different ethnic, gender, and regional experiences…this recognition of diversity is crucial for broadening and deepening coalitions with social actors, both in the United States and in Mexico" (Fox and Rivera-Salgado 2004:45-46).

Until recently, the indigenous population had moved mainly within Mexico, especially toward urban areas, rather than undertaking the trek across the US-Mexico border. Within Mexico, the trend toward a movement of people out of the south toward the United States could potentially create labor shortages in a part of the country that paradoxically already relies in part on immigrant labor (including undocumented immigrants) from Guatemala. A major limitation of the data we have relied upon in this research is that the only information we have about the individual migrants is their age, sex, and place of birth. Thus, our inferences about the factors that might have prompted their own migration are based on state-level aggregations, and we do not wish to fall into the potential trap of an ecological fallacy. However, we can conclude that states that send disproportionate shares of migrants tend to be those with below average social and economic infrastructures. This is especially true of the states from which we see the most rapid recent increase in the propensity to send migrants to the United States. In sum, the origins of migrants detained by the U.S. Border Patrol offer a picture of significant changes taking place that will have potentially far-reaching effects in both Mexico and the United States.

2.6 NASA REASoN Project Outcome List

Theses and dissertations

Completed

Anguelova, Z. 2007. Integrating Fire Behavior and Trafficability Models to Assess Fire Danger to Pedestrians Within the San Diego-Mexico Border Zone. Master's thesis. San Diego State University.

Cao, L. 2004. Generating and Updating Maps of Undocumented Immigrant Trails Along the U.S.-Mexico Border Using Airborne Digital Multispectral Imagery. Master Thesis. San Diego State University.

Hong, J.E. 2007. Dynamic Multi-user Tracking in Wireless Environments with Mobile Geographic Information Systems (GIS) and Web-based Campus Mapping Applications for Monitoring Campus Crime: A Case Study at San Diego State University. Master's thesis. San Diego State University.

Lathrop, S. 2009. Updating Maps of Foot Trail Networks for the US-Mexico Border Zone Using Semi-automatic Feature Extraction Methods and Very High Resolution Remotely Sensed Imagery. Master's thesis. San Diego State University.

Yang, D.D. 2004. Integrating Real-time Mobile Computing and Web-based GIS for Campus Security Management. Master Thesis. San Diego State University.

Zhang, T. 2008. Developing Grid-enabled Internet GIServices to Support Geospatial Cyberinfrastructure: A Pilot Study in Accessibility. Doctoral dissertation. San Diego State University.

In-progress (projected completion date)

Giovando, C. 2009 (Planned). Analysis of Human Migration Behavior Along the U.S.-Mexico Border in the San Diego County Using an Origin-Destination Approach. Master's thesis. San Diego State University.

Fraley, G. 2009 (Planned). Integrating a Multi-Objective Genetic Algorithm with a Geographic Visualization and Analysis System: an Application to Hazard Mitigation. Master's thesis. San Diego State University

Lippitt, C. 2011 (Planned). Time Sensitive Remote Sensing. Doctoral Dissertation. San Diego State University

Refereed publications

Completed

Anguelova, Z., Stow, D., Kaiser, J., Dennison, P. and Cova, T. 2009. Integrating fire behavior and pedestrian mobility models to assess potential risk to humans from wildfires within the US-Mexico border zone. *Professional Geographer*. Accepted May 2009.

Cao, L., Stow, D., Kaiser, J. and Coulter, L. , 2007. Monitoring Cross-border Trails Using Airborne Digital Multispectral Imagery and Interactive Image Analysis Techniques, *Geocarto International*, 22(2): 107-125.

Coulter, L. and D. Stow. 2008. Assessment of the Spatial Co-registration of Multitemporal Imagery from Large Format Digital Cameras in the Context of Detailed Change Detection. *Sensors*, 8:2161-2173. .

Jankowski, P. 2007. A Rough Set-Based Approach to Handling Uncertainty in Geographic Data Classification. In: A. Moris and S. Kokhan (eds.), Geographic Uncertainty in Environmental Security. Springer Verlag, Berlin, pp. 75-87.

Kaiser, J., Stow, D., Cao, L. and Coulter, L. 2004. Evaluation of Remote Sensing Technologies for Mapping Trans-border Trails. *Photogrammetric Engineering & Remote Sensing*, 70 (12): 1441-1447.

Stow, D. and Niphadkar, M. 2007. Stability, normalization and accuracy of MODIS-derived

estimates of live fuel moisture for southern California chaparral. *International Journal of Remote Sensing Letters*, 28(22): 5175-5182.

Tsou, M.H. 2004. Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management. *Cartography and Geographic Information Science*, 31(3): 153-165.

Tsou, M.H. 2006. Bridging the Gap: Connecting Internet-based Spatial Decision Support Systems to the Field-based Personnel with Real time Wireless Mobile GIS applications. In *Collaborative Geographic Information Systems*, S. Balram and S. Dragicevic (Eds.), pp. 316-339 (Idea Group, Inc.).

Tsou, M.H., Guo, L. and Howser, T. 2005. A Web-based Java Framework for Cross-platform Mobile GIS and Remote Sensing Applications. *GIScience & Remote Sensing*, 42(4): 333-357.

Tsou, M.H., Stow, D. and J. Kaiser. 2006. Spatial Decision Support Services Enhance Homeland Security. *GeoIntelligence,* Mar/Apr 2006:18-23.

Tsou, M.H. and Sun, C.H. 2007. Mobile GIServices Applied to Disaster Management, Book chapter in *Dynamic and Mobile GIS: Investigating Change in Space and Time*. (edited by Drummond, J, Billen, R., Forrest, D. and Joao, Ed. 2006. published by CRC Press, Taylor & Francis. (Innovations in GIS book series), pp. 213-236.

Weeks, J., J. Stoler, and P. Jankowsky. Who's Crossing the Border: New Data on Undocumented Immigrants to the United States. *Population, Space and Place*. Accepted for publication March 2009.

Zhang, T. and Tsou, M.H. 2005. The Integration of Grid-enabled Internet GIServices and Geographic Semantic Web Technologies. *Geographic Information Science,* 11(1): 15-23.

Submitted or Planned (include target journal and submission date)

Coulter, L., Hope, A., Lippitt, and Stow, D. Detecting Landscape Disturbance Along the US-Mexico Border Using Thematic Mapper Time-series Data. *Photogrammetric Engineering and Remote Sensing*. Planned submission August 2009.

Jankowski, P., Giovando, C., Weeks, J., Wilkes, M. Geovisual Analytics Methods for Tracking Illegal Immigration Patterns along the San Diego County Sector of the U.S. – Mexico Border. *Computers, Environment and Urban Systems*. Planned submission Fall 2009.

Lathrop, S., Stow, D., Kaiser, J., Coulter, L. and Hope, A. Updating Maps of Foot Trail Networks for the US-Mexico Border Zone Using Semi-Automatic Feature Extraction Methods and Very High Resolution Remotely Sensed Imagery, *Photogrammetric Engineering & Remote Sensing.* Planned submission July 2009.

Conference proceedings papers

Completed

Giovando, C. and Zhang, T. 2005. Spatial Knowledge Discovery Through an Integration of Visual Data Exploration with Data Mining. In *UCGIS Summer Assembly*, June 2005, Jackson Hole, WY.

Coulter, L., Lathrop, S. and Stow, D. 2005. Detailed Change Detection Using High Spatial Resolution Frame Center Matched Aerial Photography. *20th Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, October 2005, Weslaco, TX.

Coulter, L. and Stow, D. 2007. Classifying Vegetation Fire Fuels using Multispectral Imagery and LIDAR-derived Vegetation Height and Density. *21st Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, May 2007, Terre Haute, IN.

Conference presentations

Completed

Coulter, L., Lathrop, S. and Stow, D. 2005. Detailed Change Detection Using High Spatial Resolution Frame Center Matched Aerial Photography. *20th Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, October 2005, Weslaco, TX.

Coulter, L. and Stow, D. 2007. Classifying Vegetation Fire Fuels using Multispectral Imagery and LIDAR-derived Vegetation Height and Density. *21st Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imaging for Resource Assessment*, May 2007, Terre Haute, IN.

Coulter, L, and D. Stow. 2009. Monitoring the International Land Borders of the United States Using High Resolution Imagery. Presentation at the JACIE (Joint Agency Commercial Image Evaluation) conference, April 2009, Fairfax, VA.

Giovando, C. and Zhang, T. 2005. Spatial Knowledge Discovery through an Integration of Visual Data Exploration with Data Mining. *UCGIS Summer Assembly,* June 2005, Jackson Hole, WY.

Giovando, C., Rizzo, L. and Long, S. 2005. A Look at the Border. *ESRI International User Conference,* July 2005, San Diego, CA.

Stow, D. 2004. A Spatial Decision Support System for Border Security. *University Consortium for Geographic Information Science, Congressional Breakfast Presentation,* February 2004, Washington D.C.

Stow, D. 2005. Border Security Decision Support System. *Annual Meeting of the American Society of Photogrammery and Remote Sensing,* March 2005, Baltimore, MD.

Tsou, M.H. 2005. Internet-Based Spatial Decision Support System with Real-Time Wireless Mobile GIS. *ESRI International User Conference,* July 2005, San Diego, CA. (Abstract URL: http://gis.esri.com/library/userconf/proc05/abstracts/a1115.html)

Zhang, T., Giovando, C. and Jankowski, P. 2005. Spatial Knowledge Discovery through an Integration of Visual Data Exploration with Data Mining. *American Association of Geographers 2005 Annual Meeting*, April 2005, Denver, CO.

Community (national and local) presentations

Completed
Stow, D. and Weeks, J. 2006. Spatial Decision Support System for Border Security. *Presentation at Department of Homeland Security Science and Technology Headquarters*, March 2006, Washington D.C.

Stow, D. and Weeks, J. 2006. Spatial Decision Support System for Border Security. *Presentation at Department of Homeland Security Science and Technology Headquarters*, March 2009, Washington D.C.

Project reports

Completed
Kaiser, J. and Stow, D. 2004. Tunnel Location Predication Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kaiser, J. and Stow, D. 2006. Model Guide: Clandestine Airfield Location Predication Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kaiser, J., Stow, D., and Krall, D. 2007. Logic Model: Border Foot Trafficability Prediction Model. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kaiser, J and L. Coulter. 2007. Digital Elevation Model Assessment for Border Viewshed Analysis. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kaiser, J., T. Zhang, and M. Tsou. 2008. Integrating Real-time National Weather Service Information for the San Diego Border Region. Department of Geography, San Diego State

University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kim, I., J. Kaiser, T. Zhang, and M. Tsou. 2008. Integrating Real-time National Weather Service Information for the San Diego Border Region - **Supplemental Report**. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Kim, I., Y. Tsai, and M. Tsou. 2008. New Technologies of Mobile GIS. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Fraley, G., C. Giovando, and P. Jankowski. 2008. Organized Visual Data Mining of Immigration Propensity. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Tsou. 2005. Mobile GIS Technology Summary. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Coulter, L., D. Stow, M. Rosa, S. Lathrop, and T. Dougherty. 2009. Assessment of Commercial High Spatial Resolution Imagery for Border Monitoring. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

In-progress

Coulter, L. and Stow, D. 2007. Utility of LIDAR Data for Quantifying and Characterizing Vegetation Height, Density, and Structure. Department of Geography, San Diego State University. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Technical briefing or training documents

Completed

Anguelova, Z., J. Kaiser, and L. Coulter. 2007. Wildland Fire Danger Map Models: Wildland Urban Interface Evacuation (WUIVAC) model and Pedestrian Trafficability Logic Model (PTLM). Training document delivered 18 September 2007.

Coulter, L. 2007. Using Layerstacks of Frame Center Matched Multitemporal Red Waveband Imagery for Detailed Change Detection. Briefed at San Diego State University, Department of Geography 02 August 2007.

Jung, C. and M. Tsou. 2008. The Integration of Google API and ArcGIS Web Services. A NASA Research, Education, and Application Solutions Network (REASoN) technical note.

Kaiser, J. 2004. Tunnel Location Prediction Model. Briefed at San Diego Sector Headquarters, September 2004.

Kaiser, J. 2005. Tethered Airborne Radar System (TARS) Fade Analysis. Briefed at San Diego Sector Headquarters, 2005.

Kaiser, J. 2006. Clandestine Airfield Location Prediction Model. Briefed at San Diego Sector Headquarters, May 2006.

Kaiser, J. K. 2006. Digital Elevation Model Assessment for Border Viewshed Analysis. Briefed at SDSU Dept. of Geography 13 Dec. 2006 (?).

Kim, I., and M. Tsou. 2008. The Integration of NASA Remote Sensed Imagery Products and Other Satellite Imagery for San Diego 2007 Wildfires. A NASA Research, Education, and Application Solutions Network (REASoN) Project Report.

Wilkes, M. and P. Jankowski. 2006. Dividing the Border Into Homogeneous Segments. Department of Geography, San Diego State University.

Software tools

Completed

Anguelova, Z. Model consisting of a series of software tools for calculating fire evacuation trigger buffers (ETBs). Includes fire spread model component based on FlamMap, fire rate of spread algorithm, and a shortest path algorithm (Dijikstra, 1959).

Coulter, L. 2008. ERDAS Imagine spatial model for automated relative radiometric normalization of multitemporal airborne image mosaics. ERDAS Imagine software.

Giovando, C. 2005. An automated scripting set for conversion and formatting of Enforced Integrated Dataset from the Border Patrol. SPSS syntax scripts. Not for public distribution.

Giovando, C. 2005. A customized and extensible Plone website for internal REASoN project use and collaboration. Plone CMS and Python. **Not for public distribution**.

Kaiser, J. GIS model for predicting potential tunnel locations. Arc/GIS software. **Not for public distribution**.

Kaiser, J. GIS model for predicting clandestine airfield locations. ArcGIS software. **Not for public distribution**.

Kaiser, J. GIS model for predicting pedestrian rates of travel in the border region. ArcGIS software. **Not for public distribution**.

Wilkes, M. 2006. A visual interface to calculate segmentation clusters using fuzzy k-means iterations sensitivity analysis. ESRI ArcGIS, and Python. **Not for public distribution**.

Academic Reports

Completed

Giovando, C. 2004. A Bayesian Modeling Approach to Predict Illegal Immigrants Presence in the San Diego County Sector. Department of Geography, San Diego State University.

Giovando, C. 2005. Descriptive and Comparative Analysis of the Entire Border EID 2002-2004. Department of Geography, San Diego State University.

Giovando, C. 2005. Descriptive and Comparative Analysis of the San Diego Sector EID 2002-2005. Department of Geography, San Diego State University.

Giovando, C. 2005. Reference Procedure for Processing the EID. Department of Geography, San Diego State University.

Giovando, C. 2006. People Smuggling Business Along the U.S.-Mexico Border in the San Diego County. Department of Geography, San Diego State University.

Giovando, C. 2006. Segmentation of the U.S.-Mexico Border in the San Diego County Using the Rough Sets Approach. Department of Geography, San Diego State University.

Giovando, C. 2006. Socio-demographic Analysis of Profiles of Illegal Mexican Immigrants in the San Diego Sector Using a Rough Sets Rules Generation Approach. Department of Geography, San Diego State University.

Giovando, C. 2006. Origin-Destination Analysis of Mexican Illegal Immigration in the San Diego Sector. . Department of Geography, San Diego State University.

Wilkes, M and P. Jankowski. 2006. Dividing the Border into Homogeneous Segments: A Step by Step Description. Department of Geography, San Diego State University.

Zhang, T. 2004. Summary of Analysis of 2002 - 2004 EID Apprehension Data. Department of Geography, San Diego State University.

Derived maps, GIS layers, or imagery data sets (includes modeling results)

Completed

ArcIMS Demo for Border Spatial Decision Support (secured version) https://geoinfo.sdsu.edu/website/reasonprivate/ A Web mapping service prototype for Border Spatial Decision Support Systems with security protection (encrypted data transmission).

ArcIMS Demo for Border Spatial Decision Support (public access version) http://geoinfo.sdsu.edu/website/reasonpublic/ A Web mapping service prototype for Border Spatial Decision Support Systems with no security implementation (to compare the performance with different security methods).

Baja California road layer in ArcGIS shapefile format converted and edited from INEGI DXF dataset. Department of Geography, San Diego State University.

2004 Color Infrared Aerial Photo Mosaics. August 2004. One foot and six inch spatial resolution. Imagery acquired May 2004. ERDAS Imagine format. Department of Geography, San Diego State University.

2005 Color Infrared Aerial Photo Mosaics. August 2007. Six inch spatial resolution. Imagery acquired July and August 2005, and precisely registered to 2004 data for change detection purposes. ERDAS Imagine format. Department of Geography, San Diego State University.

Formatted and interoperable EID 7 levels of detail derived from original Border Patrol files, for each fiscal year and entire period 2002-2006.

Improved reference database for Mexican localities matching in the Enforced Integrated Database, based on apprehension data available for the San Diego Sector 2002-2006. Department of Geography, San Diego State University.

KML files for time series visualization in Google Earth of density of apprehensions in the San Diego Sector 2002-2006.

Google Map Demo for Border Spatial Decision Support http://geoinfo.sdsu.edu/reasondemo/.
A Google-mashup prototype for Border Spatial Decision Support Systems.

Landsat TM/ETM Image Time-series Data Set. 2005. Nine image scenes acquired between 1991 and 2005. Calibrated to values of reflectance, and precisely co-registered. ERDAS Imagine format. Department of Geography, San Diego State University.

LIDAR-based Vegetation Height Raster Map. August 2006. Derived from LIDAR point data for 2 mile by 12 mile border strip (Marron Valley to eastern Tecate). ERDAS Imagine format. Department of Geography, San Diego State University.

Porosity index layer of homogeneous segments regarding penetration difficulty of the San Diego Sector. Department of Geography, San Diego State University.

Reference geodatabase for matching countries names and codes from the EID to the international standard ISO nomenclature. Department of Geography, San Diego State University.

San Diego Emergency Response GIS Data Portal (http://geoinfo.sdsu.edu/metadataexplorer/explorer.jsp) This web site is dedicated to providing GIS metadata catalog services for the San Diego County emergency response purpose.

San Diego Vector Map of Primary Trans-border Trails. October, 2004. ArcGIS shapefile. Department of Geography, San Diego State University. **Not for public distribution**.

San Diego Vector Maps of Border Roads (Class A, B, and C) and Arroyos. October, 2004. ArcGIS shapefile. Department of Geography, San Diego State University. **Not for public distribution**.

San Diego Vector Point Map of Border Infrastructure such as Buildings. October, 2004. ArcGIS shapefile. Department of Geography, San Diego State University. **Not for public distribution**.

GIS Model-derived Map of Potential Aircraft Landing Sites in San Diego County. January, 2006. ArcGIS shapefile. Department of Geography, San Diego State University. **Not for public distribution**.

GIS Model-derived Map of Suitable Tunnel Locations along San Diego County/Mexico International Border. November, 2004. ArcGIS shapefile. Department of Geography, San Diego State University. **Not for public distribution**.

3.0 Metrics and Technology Transfer

3.1 REASoN Project Metrics: USBP Survey

The REASoN team at San Diego State University provided a survey to the San Diego and Grand Forks Sectors of the USBP with the purpose of obtaining metrics about the current implementation and anticipated future implementation of project outcomes into USBP operations. The survey questions listed in Figure 3-1 were submitted to the USBP for each of these 21 SDSU REASoN project outcome areas:

- FREQUENT HIGH RESOLUTION IMAGE COLLECTION AND MONITORING
- BORDER TRAIL MAP FOR SAN DIEGO COUNTY
- SEMI-AUTOMATED CHANGE DETECTION WITH HIGH RESOLUTION IMAGERY
- MICRO UNMANNED AERIAL VEHICLE IMAGING
- LANDSAT TM TIME SERIES DATASET
- LIDAR DATA PRODUCTS FOR TERRAIN AND VEGETATION ASSESSMENT
- SHUTTLE RADAR TOPOGRAPHIC MISSION (SRTM) TERRAIN DATA
- DIGITAL ELEVATION MODEL ASSESSMENT FOR BORDER VIEWSHED ANALYSIS
- TUNNEL LOCATION PREDICTION MODEL
- BORDER FOOT TRAFFICABILITY PREDICTION MODEL
- CLANDESTINE AIRFIELD LOCATION PREDICTION MODEL
- AIRCRAFT FADE LOCATION ANALYSIS
- FIRE DANGER ANALYSIS
- BORDER POROSITY
- SPATIAL AND TEMPORAL PATTERNS OF ILLEGAL IMMIGRATION
- SPATIAL DATA MINING
- STANDARDIZED MEXICAN STATE AND MUNICIPIO NAMES IN ENFORCE DATABASE
- TIME SERIES VISUALIZATION TOOLS
- WEB-BASED AUTOMATIC WEATHER MAPPING SERVICES FOR SAN DIEGO BORDER REGION
- SAN DIEGO 2007 WILDFIRE GIS DATA AND MAPPING SERVICES
- WIRELESS MOBILE GIS APPLICATIONS

The San Diego Sector responded to the survey, and their completed surveys are provided below. Figure 3-2 through Figure 3-5 provide a summary of San Diego Sector responses for all REASoN project outcome areas combined. From Figure 3-2 through Figure 3-5, it is apparent that the San Diego Sector intends to transition the SDSU REASoN project outcomes to "some utilization" or "fully operational." However, at the current time most outcomes are considered as "planned for implementation", "under consideration", or "not at all implemented." There were a variety of reasons for not likely implementing some REASoN project products, tools, techniques, and knowledge; and none stand out above the rest (Figure 3-4). However, it is clear that implementation of REASoN project outcomes will assist the USBP by providing new

information/intelligence, improved situational awareness, and increased interdiction success (Figure 3-5).

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

_____

_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

_____

_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

_____

_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
___ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any)_____

_____

_____

Figure 3-1. Survey questions submitted to the USBP by SDSU for each of 21 REASoN project outcomes for the purpose of metrics reporting.

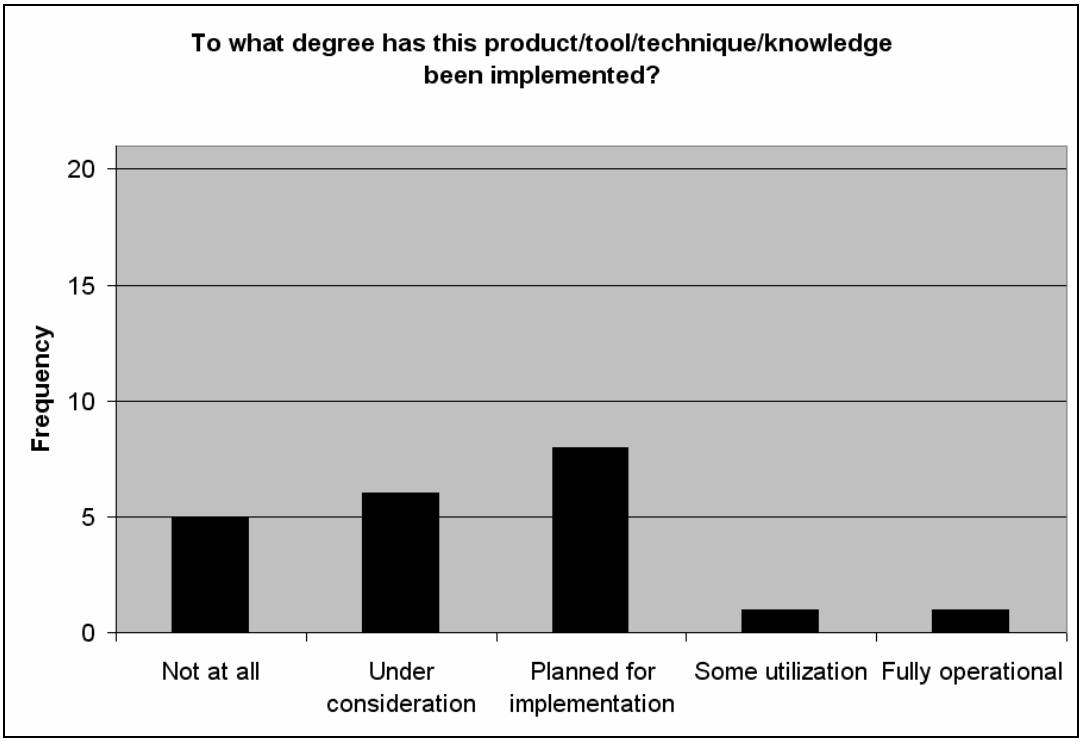

Figure 3-2. San Diego Sector responses to survey question #1.

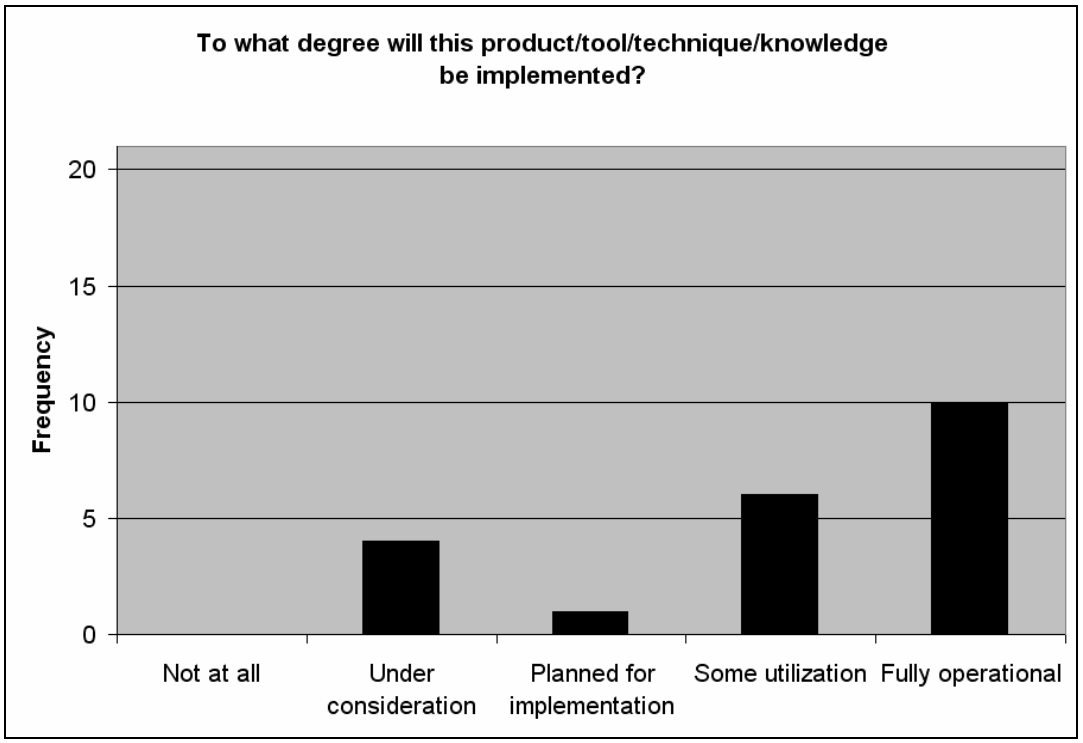

Figure 3-3. San Diego Sector responses to survey question #2.

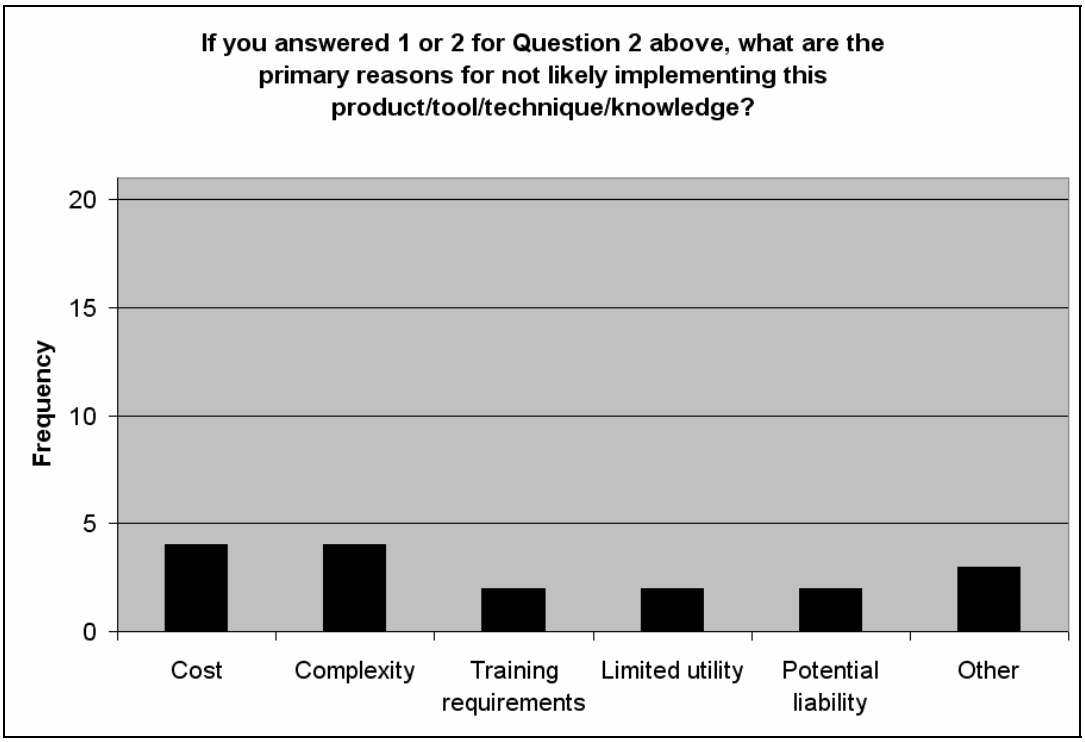

Figure 3-4. San Diego Sector responses to survey question #3.

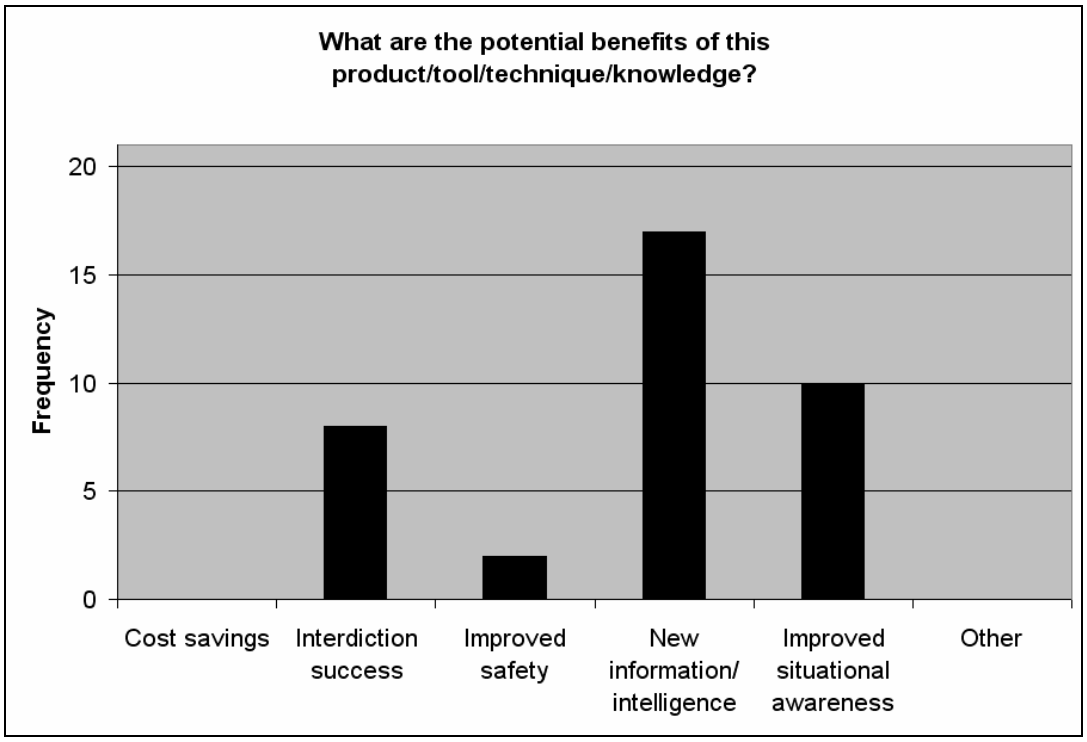

Figure 3-5. San Diego Sector responses to survey question #4.
Metrics Survey Responses from the San Diego Sector of the USBP

FREQUENT HIGH RESOLUTION IMAGE COLLECTION AND MONITORING

Description: This outcome pertains to techniques for generating precisely co-registered image mosaics covering the border tactical zone at very high spatial resolution (0.15 to 1.0 m or 6 in to 3 ft.), several times per year, and used for efficient extraction of land surface features of interest to USBP from this imagery. Imagery sources that have been evaluated include commercial large format digital camera systems (Leica ADS40, Intergraph DMC, and Vexcel UltraCam), medium format digital camera systems (e.g., Team Condor ADS SpectrView and SDSU ADAR imagery), and/or scanned color infrared film. The goal of frequent high resolution image collection and monitoring is to detect and locate changing patterns of illegal activity in the border region.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

x Cost	___ Limited utility
___ Complexity	___ Potential liability
___ Training requirements	___ Other

Comments (if any) Cost would be the number one issue. If any of the mosaic work would need to be done on site, then training and software costs would be some additional concerns.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings	x New information/intelligence
___ Interdiction success	x Improved situational awareness
___ Improved safety	___ Other

Comments (if any) The ability to do in-house change detection and feature extraction are the key benefits to this product. New and constantly updated imagery would be a welcome tool in our GIS efforts, should we be able to implement this outcome.

BORDER TRAIL MAP FOR SAN DIEGO COUNTY

Description: A map of primary cross-border trails for the San Diego County portion of the U.S./Mexico border was created by SDSU REASoN project personnel and provided to the San Diego Sector of the United States Border Patrol. This map was created by interpreting high spatial resolution (6 inch and 1 foot) imagery acquired in May 2004 and manually digitizing primary trails. Primary trails were defined as those that appeared to be used regularly, connected with other trails or roads, and generally had a north-south orientation. The trail map extends from 0.6 miles south of the border to 5 miles north of the border. This map provides a baseline of trail conditions against which changes in trail creation and use may be compared.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) Excellent map used often when it was first produced

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) At this time, several wildfires and changing alien traffic patterns have rendered this 4 year old map somewhat obsolete. A new map with updated data is needed.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
XX Other

Comments (if any) This specific model is now four years old and is somewhat obsolete due to several major wildfires and changing alien traffic patterns.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
X Interdiction success
___ Improved safety
X New information/intelligence
X Improved situational awareness
___ Other

Comments (if any) A new map with updated data and access to the shapefiles that would be created would allow for area-specific zone activity analysis.

SEMI-AUTOMATED CHANGE DETECTION WITH HIGH RESOLUTION IMAGERY

Description: Multitemporal image data sets with high spatial resolution and accurate co-registration enable the detection of detailed land cover changes associated with human activity along the border. Changes in features such as trails, dirt roads, and infrastructure (houses, buildings, etc.) that are potentially associated with illegal activity can be readily interpreted. However, it is not practical to visually detect and manually map these changes over large areas. Mapping changes across large portions the U.S.-Mexico border zone and turning that information into actionable intelligence requires semi-automated routines to detect, map, and summarize occurrences of potentially illegal activity. Semi-automated routines implemented within several software programs (Feature Analyst, Definiens, and ERDAS Imagine Spatial Modeler) have been developed for this purpose.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) Another project USBP continues to be highly interested in.

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) If feasible, USBP GIS personnel will make use of this process

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
X Complexity
X Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any) Any planned implementation of this outcome would rely heavily on the skill sets of the current or future GIS personnel at HQ. Since this will vary, no solid prediction of future use can be made.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
X Interdiction success
___ Improved safety
___ New information/intelligence
X Improved situational awareness
___ Other

Comments (if any) Geospatial awareness is the future of a first-class predictive analysis model and a primary goal of the USBP GIS efforts. The first step toward this goal is the ability to conduct change detection in an area of interest.

MICRO UNMANNED AERIAL VEHICLE IMAGING

Description: Collection of aerial and satellite imagery is often expensive and may not be very timely due to contracting procedures, sensor availability/overpass time, and narrow time windows with appropriate weather conditions. Micro unmanned aerial vehicles (UAVs) may be used to quickly and safely collect ultra high resolution imagery (1 inch spatial resolution) at low cost. REASoN team members have built small remote and autonomously controlled aircraft with digital cameras and advanced flight electronics which can be deployed on short notice and launched/retrieved by hand from any location along the border. The ultra high resolution imagery collected by micro UAVs is useful for detailed reconnaissance of areas with limited extents for purposes of: tunnel entrance/spoil pile detection, trails, hide-outs, real-time or near real-time birds eye view, etc.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

- [x] Cost
- [ ] Complexity
- [ ] Training requirements
- [ ] Limited utility
- [x] Potential liability
- [ ] Other

Comments (if any) While on paper this product shows great potential, there will be many factors that will have to be considered before an answer to this question can be given.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

- [ ] Cost savings
- [x] Interdiction success
- [ ] Improved safety
- [x] New information/intelligence
- [x] Improved situational awareness
- [ ] Other

Comments (if any) Negative factors aside, we foresee this product possibly being used by special operation groups as well with tactical events where an "eye in the sky" is needed at a moments notice or imagery of an area of concern is needed for planning purposes.

LANDSAT TM TIME SERIES DATASET

Description: A multi-year time series of Landsat TM data (1991-2005) that are radiometrically (normalized for differences in illumination/atmospheric conditions) and geometrically registered enable applications along the border region such as identifying potential landing strips for aircraft, calculating walking travel times/resistance and accessibility, documenting fire history and hazard (fire potential), and disturbance to ecosystems resulting from human activities including border traffic and interdiction activities. Landsat imagery differs from high spatial resolution imagery in that features smaller than 30 m (100 ft) are not discriminated. However, Landsat imagery is useful for several applications requiring regular, low cost, multispectral imagery for large extents (each scene is approximately 180 km by 180 km in extent, or 33,000 sq. km).

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
_x_ Other

Comments (if any) There may only a limited amount of usefulness this outcome may produce for us due to the fact that only focused, localized products would be useful for our specific needs

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
_x_ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) A National GIS process could make use of this product when reporting in to other Government Agencies regarding long-term affects and damages due to alien traffic patterns.

LIDAR DATA PRODUCTS FOR TERRAIN AND VEGETATION ASSESSMENT

Description: Small footprint LIght Detection And Ranging (LIDAR) data provide regular, discrete measurements of terrain elevation and above ground feature heights with high accuracy. Several useful products may be derived from LIDAR data, including: digital terrain models (bare ground); digital surface models (including vegetation and other above ground obstructions); vegetation characteristic maps with information such as height above ground, density, and structure; and digital near-infrared images which have the potential to "see beneath vegetation canopies." LIDAR-derived products may be most useful to the United States Border Patrol for: viewshed analysis with accurate surface models (which include vegetation obstructions), vegetation height mapping to determine impediments to movement in the border region; orthorectifying imagery; delineating man-made structures in the border region which might conceal tunnel entrances; and creating vegetation fuel maps for fire risk assessment.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

x Cost
x Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any) LIDAR products are expensive and would require GIS personnel with advanced skill-sets in order to fully make use of them.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
___ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) If the data sets can be kept current, and the properly trained personnel are retained and trained in the use and analysis of LIDAR, then the full potential of this product can and will be realized but the USBP.

SHUTTLE RADAR TOPOGRAPHIC MISSION (SRTM) TERRAIN DATA

Description: The Shuttle Radar Topography Mission (SRTM) obtained interferometric synthetic aperature radar (IFSAR) data on a near-global scale to generate the most complete moderate-resolution digital topographic database of Earth. SRTM was an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Digital elevation model (DEM) data were generated at the US Geological Survey's EROS Data Center (EDC) by processing of the IFAR data collected during the SRTM mission. Raster DEM data are available from the EDC for the US border zones (along with other digital topographic data products) at http://edc.usgs.gov/products/elevation.html and have 30 m spatial resolution for the US side and 90 m for Mexico and Canada. The REASoN team has utilized SRTM DEMs as input to the Pedestrian Trafficability Logic Model (PTLM) as a component of the fire danger prediction study. The SRTM should be useful for regional-scale visualization and modeling exercises and provides comprehensive topographic data for the entire length of the US border zones.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____
Although we still use the 30 meter DEM described above, we have found a high resolution DEM is necessary for the majority of our needs

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
x New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any)_____

DIGITAL ELEVATION MODEL ASSESSMENT FOR BORDER VIEWSHED ANALYSIS

Description: The objective of the Digital Elevation Model Assessment for Border Viewshed Analysis is to assist the Border Patrol in determining the most suitable digital elevation model for use in the selection of border observation and sensor locations providing the greatest visibility. Terrain data sets of varying spatial resolution, vertical and horizontal acccuracy, and cost were evaluated. Terrain data sets included: LIght Detection and Ranging (LIDAR), Interferometric Synthetic Aperture Radar (IFSAR) data from Intermap Technologies and from the National Oceanic and Atmospheric Administration (NOAA), and the National Elevation Dataset (NED). While LIDAR-derived surface models are the most accurate, it was concluded that IFSAR-derived terrain products are most appropriate for border viewshed analysis.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____
Current GIS personnel at SDC HQ are in the process of reviewing this model.

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____
As our GIS efforts progress, our needs for better DEMs, terrain models and imagery sets will increase. We definitely foresee a use for this advice.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
_x_ New information/intelligence
_x_ Improved situational awareness
___ Other

Comments (if any)_____

TUNNEL LOCATION PREDICTION MODEL

Description: A tunnel location prediction model was created to identify areas astride the United States-Mexico border that are suitable and likely to be exploited for the construction of clandestine transborder tunnels. Using geographic information system (GIS) modeling techniques, suitable sites for tunnel construction are identified based upon characteristics of geology, soils, water table, transportation networks, border proximity, and other parameters. Many portions of the border are unsuitable for tunneling. Focusing search and monitoring activities in likely areas greatly reduces unproductive efforts and allows targeted deployment of active, passive and tactical tunnel detection activities.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____
The USBP is very interested in the implementation of this outcome.
Once a process for use is created, we foresee its regular use.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
X Interdiction success
___ Improved safety
X New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any)The Tunnel prediction model will be an essential part of our overall GIS perspective.

BORDER FOOT TRAFFICABILITY PREDICTION MODEL

Description: Crossing the U.S.-Mexico border on foot remains the principal method of entering the U.S. illegally for those who cannot otherwise gain entry using visas. Knowing where, in what direction and how fast illegal immigrants are moving is essential information for conducting successful apprehensions. The purpose of the Border Foot Trafficability Prediction Model is to predict rates of pedestrian travel and distance/travel-time horizons along the U.S.-Mexico Border allowing improved timing of the arrival of Border Patrol agents at suitable locations to safely conduct successful apprehensions. The logic of the model is based on the concept that land cover and terrain features influence the rate of pedestrian travel and the length of time required to travel a given distance. Inputs to the model include: pedestrian rates of march, terrain slope and aspect, vegetation impediments to movement, road and trail locations, illumination, temperature and other weather observations, and distance/duration fatigue.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
_x_ Interdiction success
___ Improved safety
_x_ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) The SDC USBP foresees the use of this model in the future, as part of an as yet undiscovered GIS predictive analysis model and within anticipated online mapping services.

CLANDESTINE AIRFIELD LOCATION PREDICTION MODEL

Description: Air trafficking of people and contraband is a threat to U.S. security that continues to evolve. Southern California and Arizona are dotted with tiny airstrips and hundreds of abandoned or clandestine ones. Drug traffickers often use these airstrips to smuggle illicit drugs into the United States. Furthermore, smugglers are known to establish clandestine airstrips near the U.S.-Mexico border to further facilitate their smuggling efforts. Knowing the location of active and inactive airfields, as well as remote sites suitable for use as temporary airfields allows law enforcement agencies to improve apprehension activities. The Clandestine Airfield Location Prediction Model uses remotely sensed imagery, terrain, obstruction maps, roads, and other geospatial data to assist in identifying existing or potential destination airfield locations. The model is developed for San Diego County, CA and can be adopted for application to other border regions.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____
The SDC USBP foresees the use of this model in future, as part of an as yet undiscovered GIS predictive analysis model

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
_x_ Interdiction success
___ Improved safety
_x_ New information/intelligence
_x_ Improved situational awareness
___ Other

Comments (if any)_____

AIRCRAFT FADE LOCATION ANALYSIS

Description: Aircraft radar fade analysis involves examination of the location of aircraft radar fades in conjunction with geospatial data and remotely sensed imagery to revealed patterns in aircraft smuggling activity useful for law enforcement countermeasures. The aircraft radar fade data is provided by the Air/Marine Operation Center (AMOC) as text descriptions with specific geographic locations of the aircraft fades. Analysis of these data include: 1) creation of geospatial data sets from text reports and 2) analysis of spatial-temporal patterns of radar fades in conjunction with ancillary data (such as imagery, maps, etc.). The goal is to generate actionable intelligence regarding the locations of existing and suspected clandestine aircraft landing strips in the regions adjoining the U.S. – Mexico border.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) The SDC USBP foresees the use of this model in future, as part of as yet undiscovered GIS predictive analysis model.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
x Complexity
x Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any) As with several previous outcomes, highly trained GIS personnel will be needed in order to use this outcome for its intended purpose.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
x Interdiction success
___ Improved safety
x New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) This model, once implemented, will assist in USBP intelligence efforts to accurately pinpoint possible narcotic offloading and staging areas.

FIRE DANGER ANALYSIS

Description: Wildfires pose a significant threat to life and property. Wildland fires can be especially dangerous to hikers, backpackers, climbers, and any person traveling on foot through rural areas, since they might not be aware of the fire's presence or its spread direction until is too late to successfully evacuate. The goal of this analysis is to reduce the risk of wildfire trapping people in wildland areas along the border by identifying specific zones where the danger of entrapment by fire may be highest (danger zones). A wildland urban interface evacuation (WUIVAC) model is combined with a pedestrian travel rate model to determine when pedestrians can no longer escape a fire without assisted evacuation by local authorities. The model incorporates the location of the pedestrian, the location of the fire, and the fire spread rate and direction. During a wildfire event, helicopters or other evacuation vehicles may be deployed to rescue people from high risk zones.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
x Limited utility
___ Potential liability
___ Other

Comments (if any) While the intrinsic value of this outcome is easily recongnizable, the methods by which it will actually be implemented will have to be considered.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
___ New information/intelligence
x Improved situational awareness
___ Other

Comments (if any) Officer safety

BORDER POROSITY

Description: The concept of border porosity denotes the difficulty of crossing the international border, outside the legal border crossings, where the difficulty is calculated as the weighted combination of physical (climate, terrain, vegetation) and man-made infrastructure variables (land use, roads, trails, sensors, Border Patrol man power, and fences). The modeling procedure results in subdividing the US-Mexico border into segments that are homogenous in terms of porosity. The segmentation can be visualized on a map thus showing the spatial variability in the difficulty/ease of crossing the border. Currently, the segmentation is computed only for the San Diego section of the border, but it could be extended to the entire southern border providing the input variable data are available.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
___ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) This model has the potential to be a key element in the USBP HQ GIS process.

SPATIAL AND TEMPORAL PATTERNS OF ILLEGAL IMMIGRATION

Description: This outcome pertains to techniques applied to the ENFORCE database to improve the Border Patrol's understanding of the spatial and temporal patterns of people being apprehended. It creates an annual (or semi-continuous) file of unduplicated persons from the ENFORCE data, and codes the place of origin, based on responses provided to the arresting officer, as well as the border sector in which the person was apprehended. These data are then compared to an external demographic database to estimate the rate of migration from different places of origin (especially from states within Mexico, and municipios within those states). The demographic and economic characteristics of places of origin are also related to the migration propensities. The goal is to monitor changes over time in the places of origin in order to predict changes in illegal immigration volume for each USBP sector.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
X New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) Excellent reference material for long-term Intel analysies within this and other governmental organizations that have an interest in traffic patterns

SPATIAL DATA MINING

Description: The spatial data mining methodology applied to the ENFORCE data set includes exploratory spatial data analysis (ESDA), pattern detection, and clustering techniques. These techniques are part of ArcGIS and CommonGIS software packages. ESDA techniques include interactive maps, dynamically linked views, and exploration of time-variant data in space. They can be applied to ENFORCE data to (i) identify spatial patterns in illegal border crossings, and (ii) uncover relationships in data leading to explanation of spatial patterns. Spatial statistics can be used to test whether or not the observed data patterns are random or systematic (statistically significant).

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
X Limited utility
___ Potential liability
___ Other

Comments (if any) At this time, we are lacking the GIS staffing necessary to conduct the appropriate analysis this outcome will provide

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
X New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) As with the previous outcome, this model will provide a methodology that will serve not only the USBP but other agencies as well.

STANDARDIZED MEXICAN STATE AND MUNICIPIO NAMES IN ENFORCE DATABASE

Description: An important finding from the NASA REASoN Demographic study component is that a considerable amount of useful information can be generated by combining the ENFORCE data on place of birth or residence with data that the REASoN team gathered from censuses and surveys about those places from which migrants came. One of the biggest constraints to this analysis, however, is the lack of consistency with which agents in the field record this information from each detainee. A REASoN project outcome pertains to the creation of a standardized list of place names, especially in Mexico, and a mandate that the question of place of birth and place of last residence be asked of every detainee by USBP agents.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
x New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any)_____

TIME SERIES VISUALIZATION TOOLS

Description: Implemented with Java technology, the time series visualization tool allows for computing in a table and simultaneously visualizing on a map, clusters of origin areas in Mexico. The origin clusters are comprised of municipios, from where the apprehended immigrants originated. Measures of clustering include spatial statistics such as Morans' I, G-statistic, and K-function. Using the time-series data for apprehensions between 1999 and 2006 the tool allows visualizing changes in the distribution and pattern of municipios, which had either above average or below average share of people leaving for the US border. The user is able to select a specific sector of the US-Mexico border and visualize changes in the pattern of origin areas with respect to this particular border sector.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
_x_ Other

Comments (if any) Have not seen nor used this particular tool.

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
___ Improved safety
_x_ New information/intelligence
___ Improved situational awareness
___ Other

Comments (if any) In writing, this sounds like an excellent tool that can be put to good use for our intelligence effort. However, without having seen the tool ourselves, we will wait to make a final implementation commentary.

WEB-BASED AUTOMATIC WEATHER MAPPING SERVICES FOR SAN DIEGO BORDER REGION

Description: All Border Patrol operations require accurate weather information and forecasts. This product (web-based mapping services) can deliver near real-time weather information and maps which can help the Border Patrol agents to be better prepared for their operations. This web-based mapping service integrates the National Digital Forecast Database (NDFD) and local San Diego GIS layers to provide critical weather information, including: precipitation, relative humidity, wind direction, wind speed, maximum temperature, minimum temperature, snow, and precipitation probability. Users can zoom-in, zoom-out or query the content of the maps. This web mapping service (ArcIMS) can be accessed from outside servers or GIS programs. The ArcIMS Link is ***http://geoinfo.sdsu.edu:8080*** *→* ***automatic****. The web-based weather information service is automatically refreshed and updated at specified time intervals daily. The prototype is running on the DEGAS (http://geoinfo.sdsu.edu/) server of the Department of Geography, San Diego State University.*

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) We are currently implementing this outcome through our in-house ArcServer mapservices

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) We anticipate creating our own version of the data service that SDSU is currently delivering via their server, based on the instructions provided.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
X Improved safety
X New information/intelligence
X Improved situational awareness
___ Other

Comments (if any) Excellent planning tool that will alert agents to areas of climate concern within San Diego Sector

SAN DIEGO 2007 WILDFIRE GIS DATA AND MAPPING SERVICES

Description: During the 2007 San Diego Wildfire events, the REASoN project team members formed a GIS volunteer group and built an on-line mapping website (http://map.sdsu.edu) for the wildfire GIS data download, emergency evacuation maps, 3D animations, geo-referenced aerial photos and satellite images. These GIS datasets and maps were all distributed on the web and updated frequently. Users are/were able to download various GIS layers (shapefiles) and satellite images (GeoTiff or JPEG). The team also developed a few ArcIMS mapping services and Google Map Mashups.

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any)_____

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

___ Cost
___ Complexity
___ Training requirements
___ Limited utility
___ Potential liability
___ Other

Comments (if any)_____

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

___ Cost savings
___ Interdiction success
x Improved safety
x New information/intelligence
x Improved situational awareness
___ Other

Comments (if any) We anticipate this product being delivered via our in-house map services, as the automated weather service has been.

WIRELESS MOBILE GIS APPLICATIONS

Description: *Mobile GIS is a mapping technology for field agents to visualize and improve their field-based data collection and management tasks. With mobile GIS, agents may capture spatial data directly in the field and, with access to a wireless communication network, the data can then be remotely transferred in real time to a central database back at the control and command center. Since 2005, several mobile GIS demonstrations and technical reports has been delivered to the Border Patrol. ESRI ArcPAD, Tracking Server, and customizable user interfaces have been introduced. A case study has been conducted for the improvement of SDSU campus security by collaborating with the Police Department of San Diego State University.*

Survey Questions

1) To what degree has this product/tool/technique/knowledge been implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) No methodology of implementation exists at this time

2) To what degree will this product/tool/technique/knowledge be implemented (circle one)?

1	2	3	4	5
Not at all	Under consideration	Planned for implementation	Some utilization	Fully operational

Comments (if any) The potential for this outcome is great, once certain issues are addressed.

3) If you answered 1 or 2 for Question 2 above, what are the primary reasons for not likely implementing this product/tool/technique/knowledge (check all that apply)?

- [x] Cost
- [x] Complexity
- [ ] Training requirements
- [ ] Limited utility
- [x] Potential liability
- [ ] Other

Comments (if any) While the USBP is very interested in mobile GIS and its application, many security, connectivity and logistical concerns must be addressed before proceeding with this model

4) What are the potential benefits of this product/tool/technique/knowledge (check all that apply)?

- [ ] Cost savings
- [x] Interdiction success
- [ ] Improved safety
- [x] New information/intelligence
- [x] Improved situational awareness
- [ ] Other

Comments (if any) Upon implementation, we anticipate many different uses for this type of technology for use by agents in the field.

3.2 Technology Transfer: Online Archive

During the period December 2007 to March 2008, Pete Coulter and Tong Zhang organized all of the REASoN outcome products and made them available on a secure web site that is accessible by project members only. REASoN project outcome products include: monthly and semi-annual project reports submitted to NASA; refereed publications; academic reports; community presentations; conference presentations and proceedings papers; final reports for individual project tasks; software tools; technical briefings and training documents; theses and dissertations; and derived maps, GIS layers, and image datasets. Web-based mapping applications developed for the REASoN project are also available from this web site. Figure 3-6 through Figure 3-9 show portions of the Reports, Outcomes, Data, and Demos web pages, respectively.

While creation of the online archive was helpful to REASoN project members at SDSU, the primary purpose was to enhance technology transfer to the USBP by making all project documents and data sets readily available to USBP personnel. USBP personnel access this site regularly as they work to implement products, tools, techniques, and knowledge derived from the project.

3.3 Technology Transfer: Professional Training using Advanced Technologies

Throughout the project, SDSU personnel have provided training sessions to USBP personnel on the use of the tools, techniques, and data sets resulting from the project. However, rapid turnover of USBP personnel has resulted in loss of the transferred technology within the USBP. Therefore, this period we evaluated the use of professional training firms using advanced technologies for broadly transferring technologies derived from the REASoN project to multiple sectors of the USBP as well as to personnel at the national headquarters. We contracted with a company called Integrated GIS Technologies, Inc (IGIST) to develop two eLearning based geospatial training modules. One is a self-paced tutorial developed with Flash software which teaches agents how to effectively and efficiently perform change detection with high spatial resolution imagery and identify/delineate new trail features and other small-area changes.

The second training module is an instructor-lead Webcast seminar delivered by invitation to a Citrix shared desktop environment. The module teaches agents how to determine the distance a pedestrian may travel from a point of initial sighting or annunciation by a sensor, give specific periods of time.

The webinar was conducted on 21 February 2008 and was recorded so that the training session may be replayed at any time. Final products for the two eLearning modules were delivered to SDSU in Feburary. These modules were also provided and/or made available online to personnel from two USBP sectors (San Diego and Grand Forks) and to participants from the USBP headquarters. Both IGIST eLearning modules can be accessed from the REASoN secure web site "Demos" page at http://geoinfo.sdsu.edu/reasonmember/demos.html. Please contact Pete Coulter at (619) 594-6973 for the username and password to access the site.

Figure 3-6. REASoN secure web site, "Reports" page.

Figure 3-7. REASoN secure web site, "Outcomes" page.

Figure 3-8. REASoN secure web site, "Data" page.

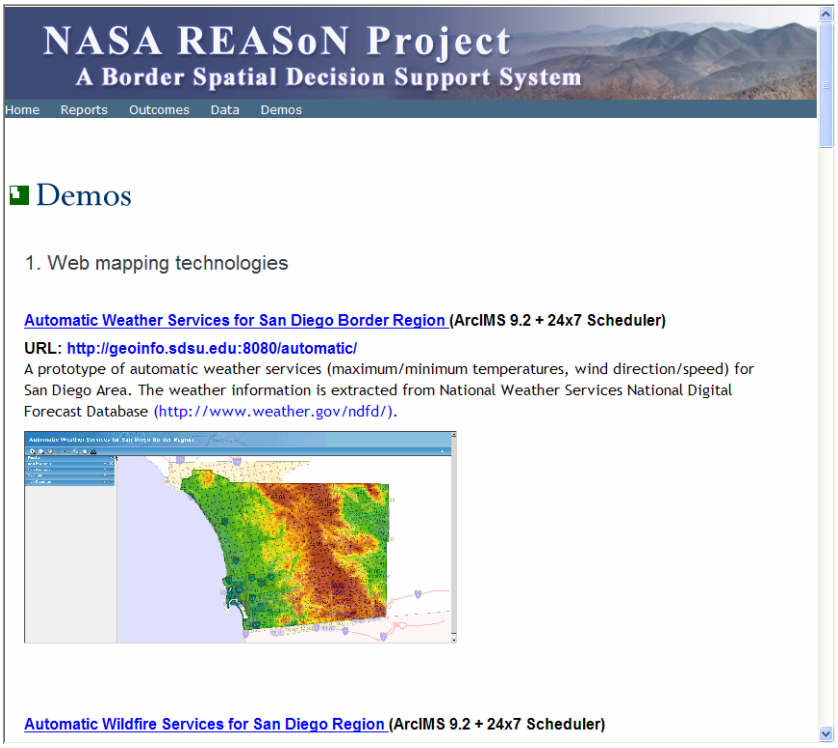

Figure 3-9. REASoN secure web site, "Demos" page.